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2018 SPECIAL ISSUE

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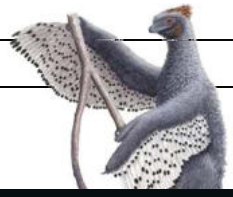


Some dinosaurs were fluffy → p19

WELCOME

I used to hate New Year's Resolutions. I mean, why wait until 1 January to make a change? And why improve myself during the dark winter months, when I can eat, drink and sleep my way through them?

I have to admit though, that the further I get from my pessimistic, block-headed 20s, the more the idea of a new year as a blank canvas appeals to me. Cancelled gym memberships and short-lived diet plans have taught me that, January or not, change is hard. National statistics tell me I'm not alone. Between 80 and 90 per cent of new diets don't last; smokers try to quit 30 times before succeeding on average; 75 per cent of people who set fitness goals give them up. For any chance of success, you've got to keep trying, and the New Year seems like the perfect time to exorcise ghosts of failures past and embrace something new.

So if, like me, you think you ought to put a little less food on your plate, leave a few bottles of wine on the shelf and spend a little less time on your phone, then we can help. Starting on p44, we explore what the science says about a Dry January, then on p52 we take a look at the latest research on dieting, and on p59 we investigate the emergence of tech detox programmes.

Or if you fancy self-improvement that's a little more cerebral in nature, turn to the centre of the magazine for our special supplement on the hottest topics in space research right now, written by cosmologist Marcus Chown.

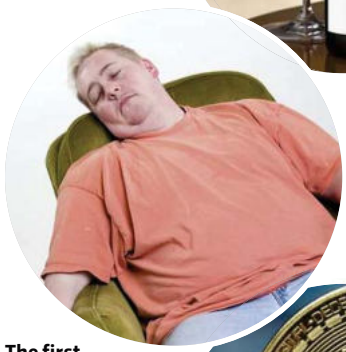
Hope you enjoy the mag, and good luck with your resolutions!

Daniel Bennett

Daniel Bennett, Editor

WHAT WE'VE FOUND OUT THIS MONTH

There are some health benefits from drinking small amounts of red wine → p48



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DR MICHAEL MOSLEY
Doing a Dry January? Health journalist and BBC presenter Michael stays off the booze for a month to see if he can reap any health benefits. → p44

EMMA YOUNG
Do we need take some time away from our tech? Award-winning health journalist Emma meets the experts who are treating tech addiction. → p59

COVER: ANDY POTTS

CONTACT US

Advertising
neil.lloyd@immediate.co.uk
0117 300 8276

Letters for publication
reply@sciencefocus.com

Editorial enquiries
editorialenquiries@sciencefocus.com
0117 314 7388

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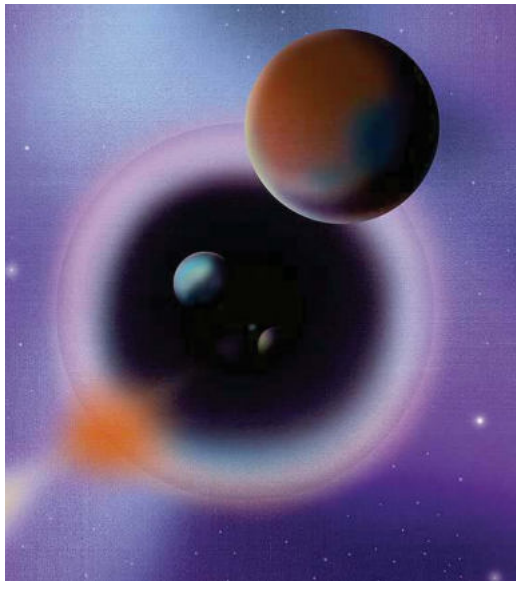

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Is your new Fitbit already gathering dust? Don't worry, the latest special edition from the *BBC Focus* team is here, and is crammed with science tips on diet, exercise and sleep.

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Flamboyant flock

LAKE NATRON, TANZANIA

Lesser flamingos, *Phoeniconaias minor*, flock en masse above an African salt lake. The water can reach temperatures of more than 40°C and is alkaline enough to burn human skin but this doesn't bother the birds, who gather to feed on the nutrient-rich bacteria and shellfish found on its shores.

The smallest of the six species of flamingo, lesser flamingos are highly nomadic and move between suitable breeding and feeding sites according to changes in weather conditions. They are highly gregarious birds and gather in large groups bound together by intricate and elaborate social structures.

"Pairs or trios or small subgroups will feed together and remain in close proximity without squabbling. Rival flamingos, or those that do not get along, will squabble, joust with bills and necks, or push and shove each other," said Paul Rose, a biologist at the University of Exeter. "Birds that are in breeding condition will gather in large groups to perform courtship displays – wing salutes, head flagging and marching are common in lesser flamingos."

However, the birds are extremely sensitive to variations in weather and water supply. Droughts and changes in water conditions caused by climate change are already threatening flamingos that traditionally gather to breed around Lake Nakuru in Kenya.

PHOTO: PHILLIP CHANG /SOLENT

City of the dead

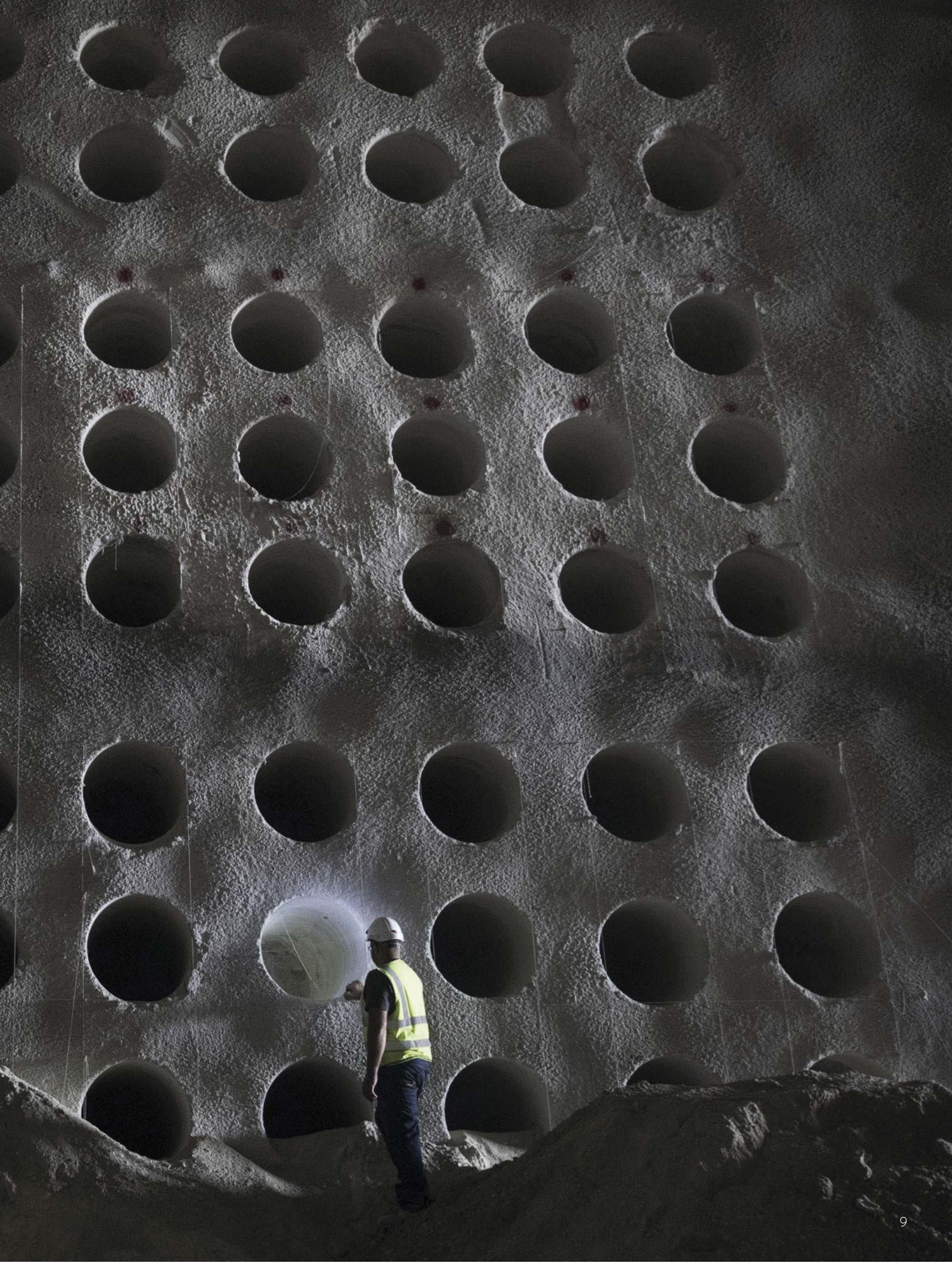
HAR HAMENUCHOT,
JERUSALEM

With burial space running out, Jerusalem's largest cemetery is expanding beneath the soil. Each of these holes will provide a final resting place for one of the city's dead, with some 22,000 graves in total in the 1.5km-long tunnel system.

A shortage of burial space is an issue in crowded cities and in regions where religion discourages cremation. This means that engineers are having to come up with innovative solutions.

These hive-like crypts were bored into the rock, 50 metres below the original cemetery. "The deceased will be buried inside the rock, just as they were in Biblical times," says Arik Glazer, chief executive of Rolzur Tunnelling, the company behind the project's construction. Visitors will enter the tunnels via elevators, with floors at different levels providing access to the stacked graves, while golf carts will be on hand to transport people around. The company plans to start burials by the end of 2018.

PHOTO: SHUTTERSTOCK



EYE OPENER

Cave in

MENDENHALL GLACIER,
JUNEAU, ALASKA

Alaska's landscape is transforming rapidly. Glacial caves, like the one pictured here, form as the ice melts in the warmer months and water burrows its way towards the ground. A stream gathers at the base and its warmth carves a tunnel through the glacier as it drives towards its terminus, in this case a lake. Every summer, this melt causes the glacier to naturally recede up the mountain, but as Alaska's climate changes the ice retreats further and further upwards, taking the caves with it.

PHOTO: CATERS NEWS

REPLY

Your opinions on science, technology and *BBC Focus*

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BBC Focus, Tower House, Fairfax Street, Bristol, BS1 3BN
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MESSAGE OF THE MONTH

Power to the people

While I think we all agree that electric vehicles are the way forward, as long as low pollution energy generation and vehicle production can be achieved, there are practical problems that appear hard to overcome.

Since many houses in this country do not have drives or front gardens, how will it be possible to charge a vehicle as the cables would run across a public footpath? Terraced houses have small frontage and residents often have difficulty parking near their property as it is a free-for-all. I cannot think of a solution to these problems and would be interested to know whether it has been considered by electric vehicle manufacturers.

Les Maud, Northampton

This year the UK government set up a £2.5m fund to solve just this problem. Electric car owners need to ask their local authorities to apply for charging points on their streets. There are also companies that solve this problem by installing wires under the pavement that emerge at the kerb. As the government tries to incentivise an electric switchover we assume more schemes like this will pop up. ***– Ed***

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a **Snowman Camera**. This connected cam lets you keep an eye on things through your PC or smartphone, via the app. It shoots HD video and boasts motion detection and 3x zoom, making it ideal as a security camera or baby monitor. For more info, visit **bigbrothersystems.com**

WORTH £75

Earth, 66 million years ago. North America is at the top, South America is bottom right, and Africa is far right

Armageddon outta here

I have followed the stories of the Chicxulub asteroid impact for many years. Back then, would the landmass of the world have been almost one giant continent? If yes, then where would the asteroid have struck and is the Chicxulub site the preserved impact point once the landmasses separated? Could the giant landmass have contributed toward the extinction due to all the life existing on one large terrain?

Henry Parr, Frome

When the asteroid struck 66 million years ago, the Earth's land masses were already drifting apart. That said, the location of the strike was pivotal as the rock there was hydrocarbon- and sulphur-rich. The impact created soot and sulphate aerosols that led to the extreme global cooling and drought that killed off the dinosaurs and led to the rise of the mammals. ***– Ed***

The vinyl word...

I am writing in response to Russell Deeks' point that a CD's 24-bit/96kHz sampling rate

PHOTOS: GETTY, SCIENCE PHOTO LIBRARY, SHUTTERSTOCK

enables more frequencies to be heard. Large scale double-blind tests show that people cannot tell the difference when higher frequencies than CD can carry are omitted, and the assertion that "what any of us can and can't hear is entirely subjective" is not true.

Keep up the good work, and a Merry Christmas to all at *BBC Focus*, including Russell!

Simon Bartlett, via email

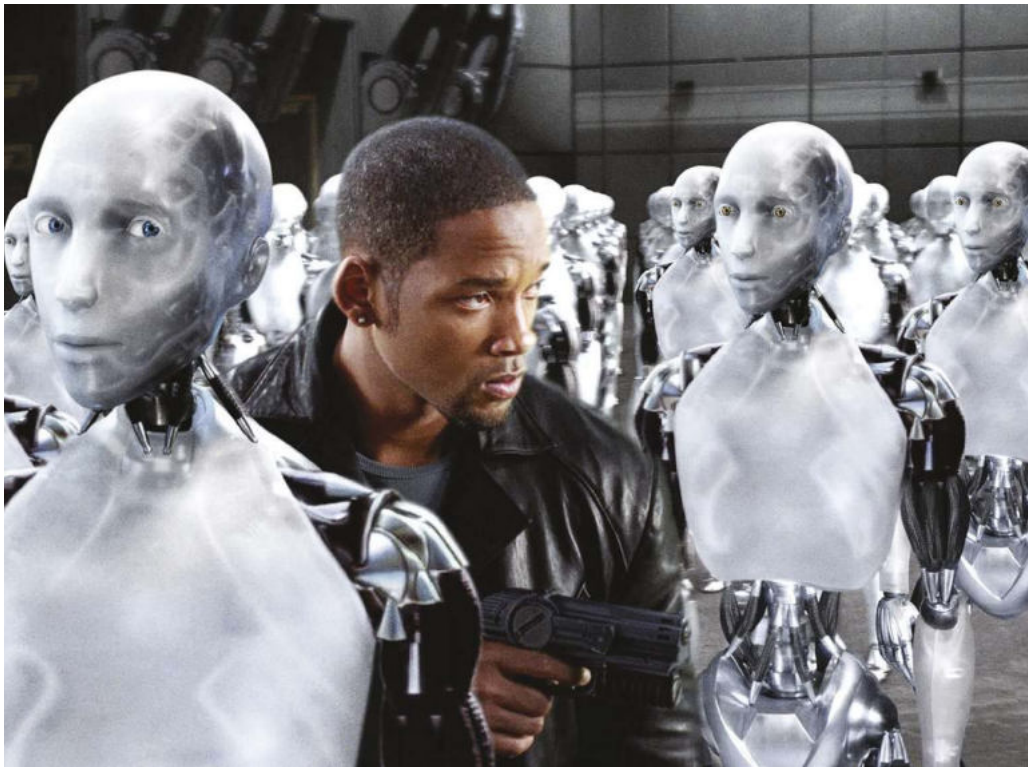
Simon Bartlett says that tests have shown that sound is not subjective

Mind machine

It was nice to see some measured views on artificial intelligence (AI) in the Christmas issue (317) from Garry Kasparov. From *I, Robot* to *The Matrix* and *2001: A Space Odyssey,* science fiction has been fuelling our anxiety about AI for decades, without nodding to the innumerable benefits. The world is full of hugely complex problems like climate change, antibiotic resistance and famine, with more variables affecting them than any human mind can handle. This is why we need the brain power of something artificial that can use brute force processing to crack these puzzles. There may be risks, but if we stand still on AI, we could be risking millions of lives.

James Munroe, Guildford

AI is not trying to kill us, no matter how creepy it looks, says James Munroe



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Production editor Alice Lipscombe-Southwell
Commissioning editor Jason Goodyer
Online editor Alexander McNamara
Staff writer James Lloyd
Contributing editors Emma Bayley, Russell Deeks

ART
Art editor Joe Eden
Designer Steve Boswell
Picture editor James Cutmore

CONTRIBUTORS
Peter Bentley, Nick Ballon, Dan Bright, JV Chamary, Alexandra Cheung-Franklin, Marcus Chown, Stuart Clark, Jamie Coe, Charlotte Corney, Simon Crompton, Helen Czerski, Emma Davies, Cathal Duane, Sam Green, Alice Gregory, Alastair Gunn, Christian Jarrett, Raja Lockey, Acute Graphics, Merijn Hos, Mark Lorch, Robert Matthews, Michael Mosley, Helen Pilcher, Andy Potts, Aarathi Prasad, Dean Purnell, Helen Scales, Kyle Smart, Luis Villazon, Emma Young.

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MOBILE
Head of apps and digital edition marketing Mark Summerton

INSERTS
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BIOLOGY

SYNTHETIC DNA MADE IN LAB

Alien organism created by adding new letters to the genetic alphabet could lead to more effective designer drugs

A team of scientists at the Scripps Research Institute in the US have created a living 'semi-synthetic' organism capable of producing proteins never seen before on Earth by adding new letters to the genetic code. The synthetic proteins created by such organisms could pave the way for a new generation of made-to-order drugs and therapies, the team said.

PHOTO: GETTY

The regular genetic 'alphabet' consists of four letters, or bases: A, T, G and C. These stand for adenine, thymine, guanine and cytosine, which are the four chemicals that make up DNA. These letters can combine in different sequences to form 20 naturally occurring amino acids – the building blocks of proteins.

In 2014, the Scripps team created two more 'letters', X and Y, making it theoretically possible to create a further 152 synthetic amino acids. However, they were unable to make an organism that could produce proteins. Now, they have successfully created an organism capable of producing so-called green fluorescent proteins by modifying *Escherichia coli* – a single-celled, rod-shaped bacterium commonly used in the lab-based manufacture of proteins.

"This is the first time that proteins have been produced in any cell by the decoding of a six-letter genetic alphabet, instead of just the natural four-letter alphabet," said study leader Dr Floyd Romesberg. "The limited combinations of the natural DNA bases, A, T, G, and C, have restricted the types of new protein therapeutics that could be made. Adding X and Y to the genetic alphabet, we now have an expanded vocabulary to be able to generate a variety of new proteins that might be developed for a wide range of applications, including as new therapeutics."

It was previously believed by many researchers that our specific DNA structure was essential for the evolution of life. However, the breakthrough by the Scripps team opens up the possibility that life could have evolved in a different way on another planet.

The organism is completely safe and has no chance of spreading out beyond the lab and contaminating natural life forms as it is incapable of producing the X and Y bases it needs to live by itself, the researchers said.

EXPANDING THE GENETIC ALPHABET

Adding additional building blocks to the DNA of *E.coli* bacteria has enabled researchers to create synthetic life forms capable of producing entirely new types of protein. Here's how they did it...

PROTEINS are large, complex molecules that are essential for life. They perform many different tasks inside our bodies such as acting as antibodies, transporting smaller molecules within cells, and transmitting signals to coordinate biological processes between different organs. They also help form many of the body's intricate structures, such as hair, skin and muscle.

There are hundreds of thousands of different proteins in the human body and many, many millions more throughout the natural world. Differences in our genes causes variation in the proteins our cells produce, which leads to diversity in our physical characteristics.

Proteins are formed when small organic compounds called **AMINO ACIDS** link together in long chains There are only 20 naturally occurring amino acids but each protein molecule contains hundreds of them joined together in a unique sequence. This gives each protein its own individual properties.

Each strand of **DNA** is made from chemicals known as **BASES**. There are four different bases – thymine, adenine, guanine and cytosine. The two strands that make up DNA's double helix are joined together by chemical crosslinks between the different bases. Thymine always pairs with adenine, and guanine with cytosine. However, the Scripps team created two new bases: X and Y. The order of the bases running along the strands forms a chemical code or set of instructions for creating proteins. Each section of DNA that codes for a particular protein is called a **GENE**.

The process of manufacturing a protein has two major steps. First, information in the DNA needed to make a specific protein is transferred to an **mRNA** (messenger RNA) molecule by a process known as transcription. During this process, thymine (T) is converted to uracil (U). A second type of RNA, **tRNA** (transfer RNA) picks up specific amino acids and returns them to the mRNA. The amino acids are lined up according to instructions on the mRNA and join together to form a protein.

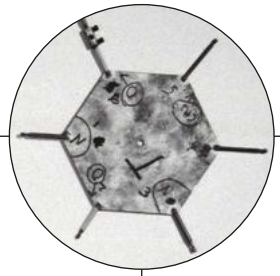
PHOTOS: GETTY X5, SYNTHORX, MADELINE MCCURRY-SCHMIDT, BILL KIOSSES/SCRIPPS RESEARCH INSTITUTE

1944

Oswald Avery (pictured), Colin MacLeod and Maclyn McCarty demonstrate that DNA is the material that makes up genes and chromosomes.

1952

Rosalind Franklin captures a detailed image of DNA using X-ray crystallography.



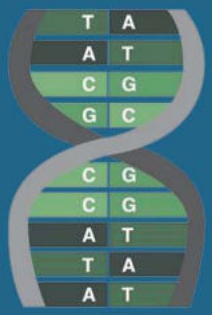
1953

Francis Crick, James Watson and Rosalind Franklin discover the double helix structure of DNA.

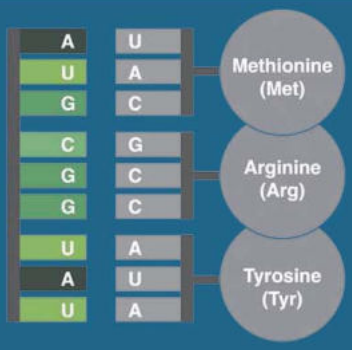
1966

Marshall Nirenberg discovers that the genetic code is made up of just four bases – adenine, cytosine, guanine and thymine.

NATURAL DNA | **DNA** → **mRNA** | **tRNA** | **AMINO ACIDS** → **PROTEINS**



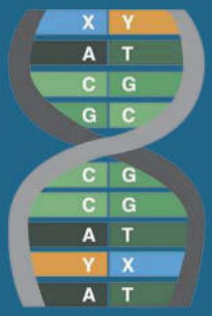
Four nucleotides (bases) are present on a DNA molecule. These are T, A, G and C. T always pairs with A, and G always pairs with C.



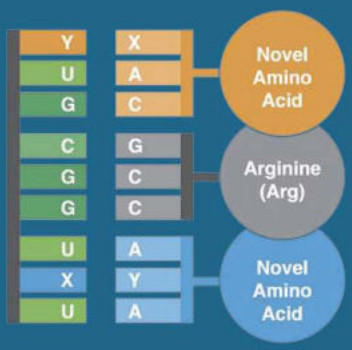
Groups of three RNA bases are called 'codons'. There are 64 of these in total, which are capable of coding for 20 amino acids.

These 20 amino acids can link up together in long chains to form different proteins.

SYNTHETIC DNA | **DNA** → **mRNA** | **tRNA** | **AMINO ACIDS** → **NOVEL PROTEINS**

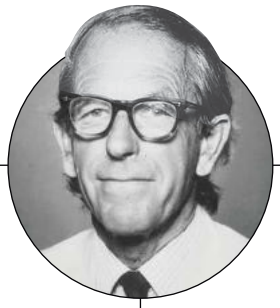


Two synthetic bases, X and Y, have been created by the Scripps team. X will always pair with Y.



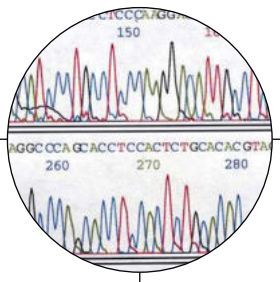
The additional two bases allow the creation of 216 codons, which can code for up to 172 different amino acids.

A greater variety of amino acids results in a more diverse selection of proteins.



1976

Frederick Sanger (pictured) and Alan Coulson devise a method for sequencing DNA. They name it the Sanger Coulson technique.



2003

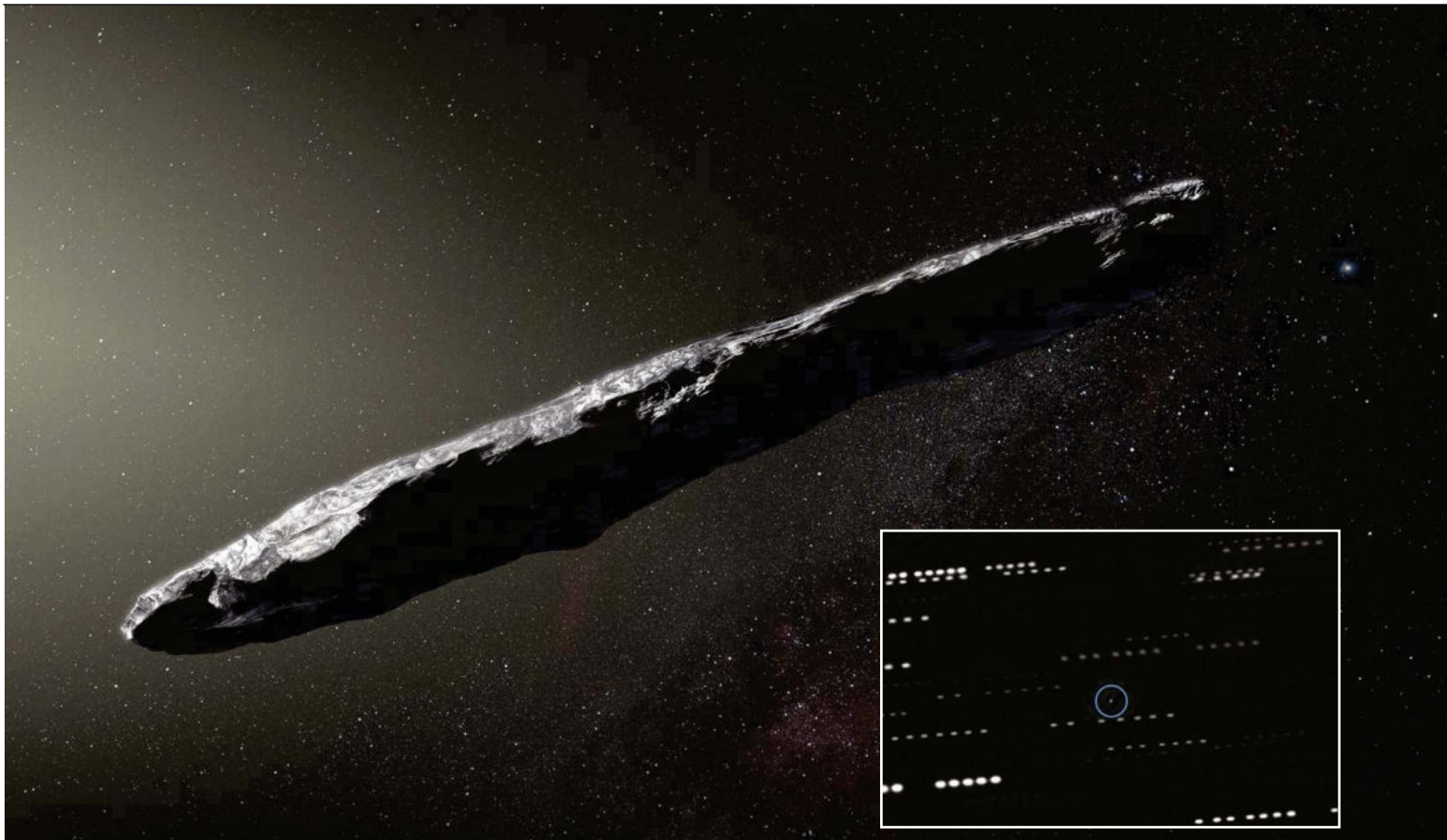
The Human Genome Project successfully maps all of the genes in the human genome.

2014

Floyd Romesberg at the Scripps Research Institute creates a strain of *E.coli* bacteria with two non-naturally occurring bases and names them X and Y.

2017

The scientists at Scripps Research Institute use their expanded genetic code to create a living 'semi-synthetic' organism.



ASTRONOMY

INTERSTELLAR ASTEROID CAPTURED ENTERING THE SOLAR SYSTEM

MAIN IMAGE: **Artist's impression of the elongated asteroid named `Oumuamua**

INSET: **`Oumuamua (marked by blue circle) photographed through telescopes**

An oddly shaped asteroid has entered the Solar System, and is the first confirmed object from another star. Officially dubbed 1I/2017 U1, but known as `Oumuamua (`Oumuamua comes from the Hawaiian word for 'scout'), the space rock was captured by the Pan-STARRS 1 telescope in Hawaii. First thought to be a comet thanks to its trajectory and high speed, `Oumuamua had already passed its closest to the Sun when it was detected, so the race was on to gather as much data as possible. At New Year, the asteroid was roughly three times the distance of the Earth from the Sun and is currently speeding away from our planet at 90,000km/h.

Telescopes can't get a good picture of `Oumuamua, but astronomers managed to determine its shape from variations in the brightness readings as the asteroid spins once every 7.3 hours.

"This unusually large variation in brightness means that the object is highly elongated: about 10 times as long as it is wide, with a complex, convoluted shape," said researcher Karen Meech. "We also found that it has a dark red colour, similar to objects in the outer Solar System, and confirmed that it is completely inert, without the faintest hint of dust around it."

`Oumuamua appears to have come from the direction of Vega, a bright star about 25 light-years away. It's estimated that such visitors arrive roughly once every year.

"We are continuing to observe this unique object," said researcher Olivier Hainaut, "We hope to more accurately pin down where it came from and where it is going next on its tour of the Galaxy. And now that we have found the first interstellar rock, we are getting ready for the next ones!"

ASTEROID OR COMET?

Asteroids and comets were born during the early days of the Solar System. Asteroids formed closer to the Sun and are made up of metals and rocky material. Comets formed further away and consist of ice, dust and rocky particles. It is the melting of the ice as a comet approaches the Sun that gives it a distinctive tail.

PHOTOS: ESO X2, REBECCA GELERNTER

PALAEONTOLOGY

SOME DINOSAURS WERE FLUFFY

This drawing is likely to be the most accurate depiction of a dinosaur ever, according to the University of Bristol team

Though films such as *Jurassic Park* show dinosaurs with tough, leathery, rhino-like skin, it has since been proved that many of them were feathered. Now, though, it seems that some dinosaurs were fluffy.

A team at the University of Bristol have studied the fossilised remains of bird-sized dinosaur *Anchiornis*, part of the same paravian group as *Velociraptor* that lived 160 million years ago. The specimen has particularly well-preserved feather details, which is something that's usually lost during fossilisation.

Covering its body, *Anchiornis* had unusual 'contour feathers' – plumage not used in flight – that were soft and V-shaped, and around one to two centimetres in length. Longer flight feathers emerged in layers from all four of the animal's limbs. *Anchiornis* seems to have needed extra flight feathers because their feathers were not 'zipped together' like a bird's feathers, so generated less lift.

The Bristol team worked closely with scientific illustrator Rebecca Gelernter, who produced this image of *Anchiornis*. The illustration shows how the dinosaur probably clung onto branches with its forelimbs, rather than perching like a bird.

"Fossil feathers in particular are very hard to interpret, even for scientists, because they preserve as flat stains derived from the feather pigments," said researcher Evan Saitta. "We could only describe the new feathers due to a fluke where some contour feathers separated from the main plumage. This drawing is likely the most accurate depiction of a dinosaur ever."

IN NUMBERS

37
YEARS

The time that NASA's Voyager 1 probe's thrusters lay dormant before being briefly fired up in November.

13.1
BILLION LIGHT-YEARS

The distance from Earth of ULAS J1342+0928, a quasar containing a supermassive black hole 800 million times the mass of the Sun. It's the most distant object of its type ever detected.

3,239

The height in metres of the UK's tallest mountain, Antarctica's Mount Hope.

ZOOLOGY

Individual Sumatran tigers are identified by their unique pattern of stripes

DEFORESTATION LEAVES SUMATRAN TIGERS DANGEROUSLY CLOSE TO EXTINCTION

Sumatran tigers are increasingly under threat due to their habitat being eaten away by deforestation, a year-long study by researchers at the University of California has found.

Though overall numbers of the tigers have gradually improved over the last two decades, the jungle in which they live is experiencing increasing threat from deforestation. It appears that 17 per cent of the tigers' environment was logged between 2000 and 2012, mostly to make way for palm oil plantations. Moreover, the team found that tiger numbers are 50 per cent higher in areas of unlogged forest, making preservation of the jungle a high priority if Sumatran tigers are to be saved from suffering the same fate as tigers on the neighbouring islands of Java, Bali and Singapore, which all went extinct during the 20th Century.

The researchers spent a year trekking through remote Sumatran forests, mounting hundreds of camera traps to video the animals whenever they passed. They found that a Sumatran tiger's home range is roughly 150 square miles, around the same size as the Isle of Wight – much larger than that of other tigers. The team discovered that there are only two habitats large enough to host more than 30 breeding females, the minimum number required to sustain populations over the long term.

"Safeguarding the remaining expanses of primary forests is now absolutely critical to ensuring tigers can persist indefinitely on Sumatra," said researcher Dr Mathias Tobler. "Large-scale reforestation is unlikely. If we are going to save Sumatran tigers in the wild, the time to act is now."

PHOTOS: FLPA, SEOKHEUN CHOI ILLUSTRATION: DANIEL BRIGHT

MATERIALS

STRETCHY SWEAT-POWERED BATTERY MADE OUT OF FABRIC

Soon you could be charging your smartphone with your sweaty socks. A team at Binghamton University, State University of New York, have created a fabric-based, bacteria-powered biobattery that could be integrated into wearable electronics.

According to the team, the microbial fuel cells could be powered by sweat generated by the human body, and produce more electricity than previous textile biobattery designs, which could be useful for wearables. "There is a clear and pressing need for flexible and stretchable electronics that can be easily integrated with a wide range of surroundings to collect real-time information," said research lead Dr Seokheun Choi. "If we consider that humans possess more bacterial cells than human cells in their bodies, the direct use of bacterial cells as a power resource interdependently with the human body is conceivable for wearable electronics."

The fuel cells use *Pseudomonas aeruginosa*, a small rod-shaped bacterium, along with a pair of electrodes coupled with a silver and silver oxide solution to produce electricity. The fuel cells were able to generate electricity in a stable manner, even when subjected to the stretching and twisting exhibited over a long lifetime.

This flexible, fabric-based biobattery could be integrated into clothes

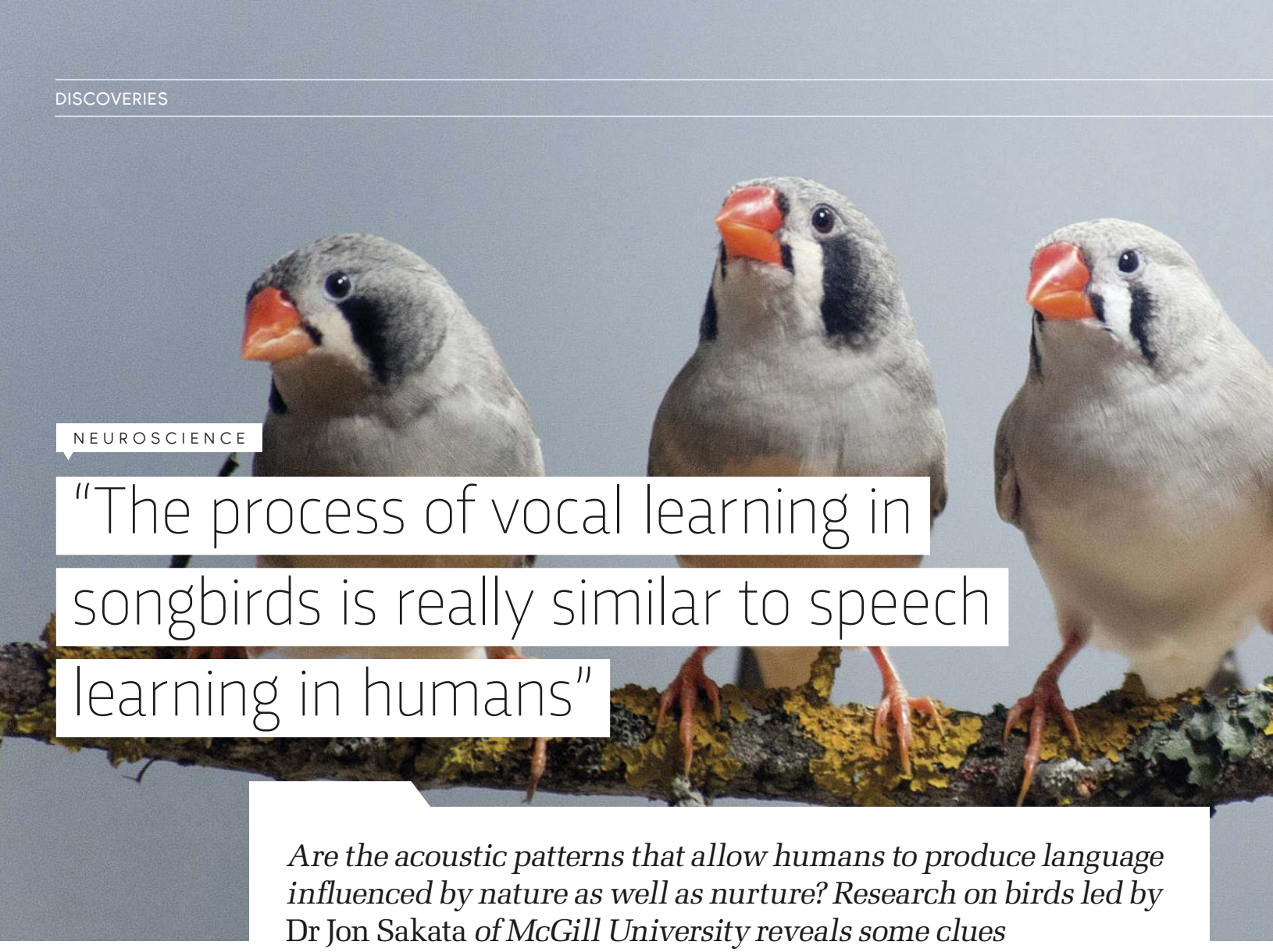
THEY DID WHAT?!

CHILDREN ENCOURAGED TO BE BATMAN

What did they do?
Researchers at the University of Pennsylvania had a group of children, aged between four and six, pretend to be Batman. They then assigned them a repetitive task and told them it was important. They encouraged the children to concentrate on the task but allowed them to take a break to play with an iPad whenever they wanted.

What did they find?
When pretending to be Batman, more than 30 per cent of the four-year-olds and more than 50 per cent of the six-year-olds spent significantly more time on the task. It's unclear whether this effect was due to the fun aspect associated with pretending to be Batman or the children identifying certain traits, such as concentration and perseverance, with being a superhero.

Why did they do that?
With more research, the team hopes to determine whether it is possible to use roleplay scenarios to teach young children valuable life skills such as perseverance.



NEUROSCIENCE

"The process of vocal learning in songbirds is really similar to speech learning in humans"

Are the acoustic patterns that allow humans to produce language influenced by nature as well as nurture? Research on birds led by Dr Jon Sakata *of McGill University reveals some clues*

What are 'universal' patterns in human speech?
Linguists studying languages around the world find they're quite diverse in structure, but there are also common features called 'universal patterns'. Why do we have these? It's possible there are cultural influences that lead to their propagation. That's one hypothesis. The other is that it's biological in origin.

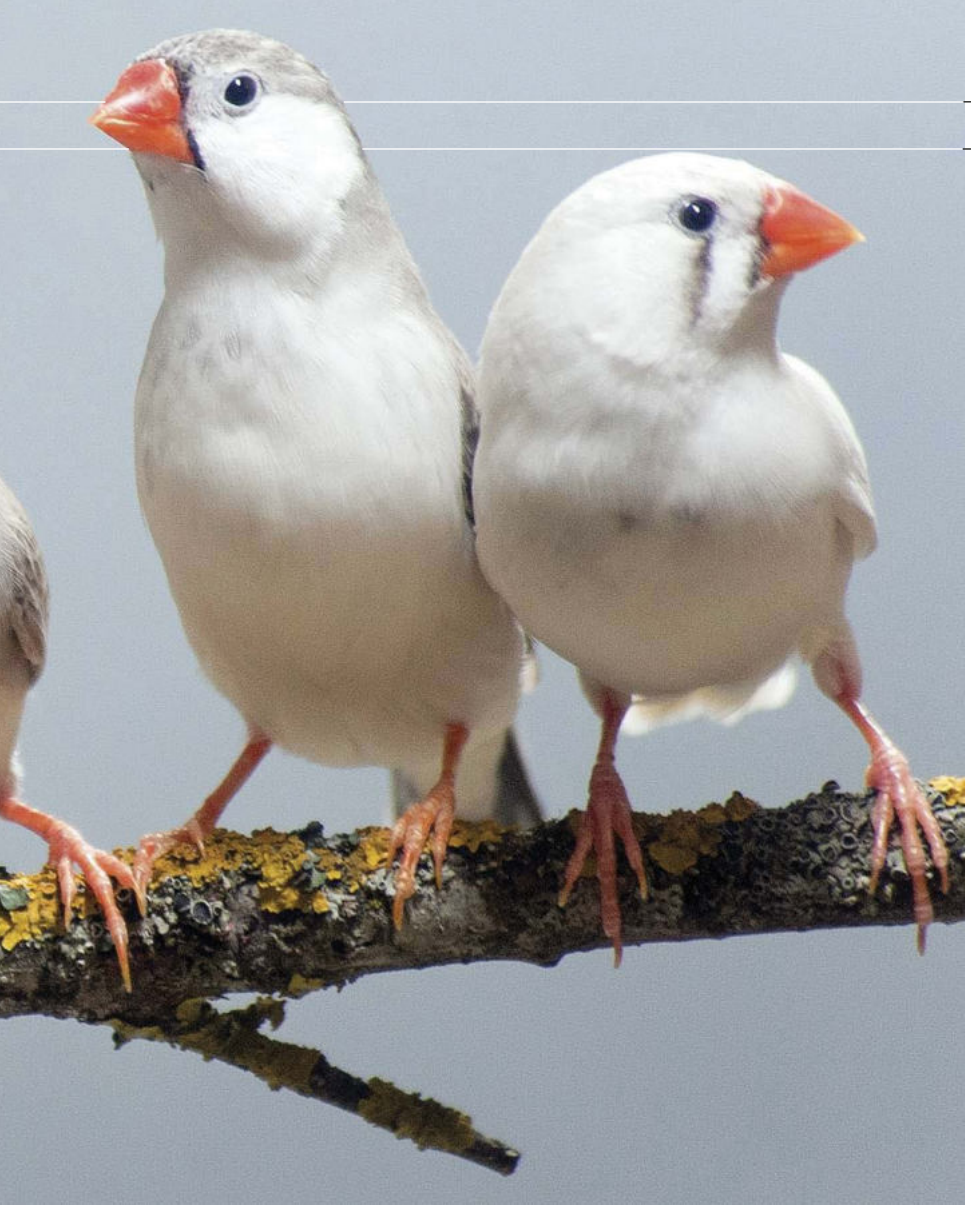
Why study acoustic patterns in songbirds?
The ideal experiment is to expose babies to patterns and see what they end up producing, but that's difficult to interpret in humans, so you do this in animal model systems. Most animals are actually born with the ability to produce vocalisations, but songbirds – like humans – learn during development.

The process is really similar to how humans learn to speak: a bird hears an adult sing, memorises it, then starts babbling. It sounds terrible initially, as if you were squeaking a rubber duck, but with time and practice their vocalisations become more species-typical. We're studying the zebra finch, endemic to the desert grasslands of Australia. Not unlike human languages, there are common features in acoustic patterns across different populations of birds. There are these universals in acoustic patterns, but we don't know whether they're cultural or rooted in biology.

How do you remove the influence of culture?
We raise zebra finches devoid of song. When the eggs hatch, we leave mum and dad in the nest for less than a week. Only the males produce complex songs, so we remove the father and just the mother takes care of the offspring. When the youngsters are able to feed themselves, we house them individually. At that point, we take five syllables common in zebra finch songs and present those to them in every sequence possible – 120 different permutations – in equal proportions and in random orders all the acoustic patterns you can produce with those five syllables. We do this for about 50 birds.

We found there were consistent patterns that birds ended up producing as adults. For example, there's what's called a 'distance call', a long syllable that has a downward sweep. If they produce those syllables, they put it at the end of their phrases. These birds are bought from pet stores but, despite that, these are patterns you

PHOTOS: SHUTTERSTOCK, DURING DN ET AL. ILLUSTRATIONS: DAN BRIGHT

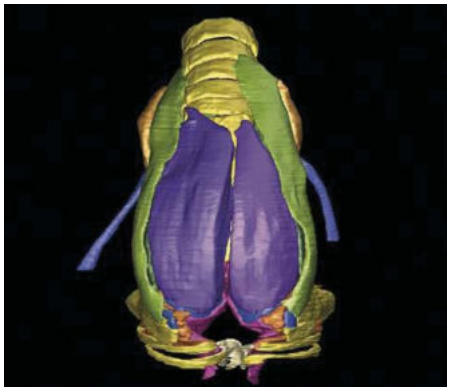


see in wild birds. That suggested at least some biological component underlies these population similarities in acoustic patterning.

So what's the biology behind learning?
Maybe the brain likes to hear particular patterns because that allows it to remember more robustly [or] maybe there is something about the vocal apparatus that makes it easier to produce those patterns – humans have a larynx or 'voice box' and birds have the syrinx, but the general properties of expiration through a pipe that has a membrane is all the same.

The brain pathways involved in vocal learning in birds are similar in humans. What we can do in songbirds is probe those neural circuits. There are hypotheses you can't experimentally test in humans that we can test in birds, to think about these burning questions in the neuroscience of speech and language, and to help lend insight into potential mechanisms.

BELOW: **The syrinx of a male zebra finch. As the song of the male is more complex, the syrinx is heavier because the muscles are larger**



BINGE-WATCHING COUPLES

Do you love settling down with your partner to watch a TV boxset? Good news – a study at the University of Aberdeen has found that watching TV shows with your other half may help engender feelings of closeness.

RETIREES

Retirees sleep an average of 20 minutes longer per night and have more restful sleep than working people, a study at the University of Turku, Finland has found. This could be because retirees have more flexible schedules and less stress.

GOOD MONTH

BAD MONTH

THE ENTIRE HUMAN RACE

It might not feel like it on a Monday morning, but you may be one of the greatest examples of the human race that will ever live. A study at Paris Descartes University has found that the limits of human lifespan, height and physical performance have been reached and are currently in decline.

FRY-UP LOVERS

Here's yet another reason why muesli is a healthier breakfast option than a full English. Droplets of oil that are released into the air when food is shallow fried can be damaging if inhaled, a team at Utah State University has found.

In this CT scan of a snailfish, its last meal of a crustacean can be seen glowing green in its stomach

MARINE BIOLOGY

DEEPEST DWELLING FISH DISCOVERED

Head 8,000 metres down into the Mariana Trench in the western Pacific and you might just bump into this guy – the Mariana snailfish, or *Pseudoliparis swirei*. Down on the seabed at this depth, conditions are hostile: pressure is around 1,000 times greater than at sea level, temperatures rarely reach 2°C, and it's almost pitch black. But the Mariana snailfish, the deepest dwelling fish ever discovered, thrives where normal fish would be squashed flat.

Researchers from the University of Washington used remote controlled traps to recover 37 Mariana snailfish on two expeditions, one in 2014 and one in 2017. The snailfish family is large, with over 400 species – but few others have the impressive abilities of the Mariana snailfish.

"THIS FISH HAS SEVERAL ADAPTATIONS TO HELP IT SURVIVE UNDER HIGH PRESSURE"

This species has none of the fearsome features of other denizens of the deep. It's a small, translucent creature, not even protected by scales. Despite this, it's a top predator of the area, swallowing tiny crustaceans whole.

"This habitat would be very harsh for us, but to the Mariana snailfish, it's home. This fish has several adaptations to help it survive under high pressure," said researcher Dr Mackenzie Gerringer. "First, it does not have any air spaces, such as a swim bladder. Air is very compressible, so the fish would have a hard time inflating a swim bladder under such high pressure. This snailfish also has adapted enzymes and a molecule called trimethylamine oxide, which helps stabilise its proteins under pressure. There are likely other adaptations that are left to be discovered!"

PHOTOS: ADAM SUMMERS/UNIVERSITY OF WASHINGTON, UNIVERSITY OF OXFORD

THINGS WE LEARNED THIS MONTH

WE CAN HEAR BETTER WITH OUR RIGHT EARS

Researchers at Auburn University, Alabama have found that we understand and retain information better if we listen primarily with our right ears. The effect is due to sound entering the right ear being processed by the left side of the brain, which controls speech and language development, they say.

DOGS ARE SMARTER THAN CATS (MAYBE)

Take that, Tiddles! A team at Vanderbilt University, Tennessee, has found that dogs have many more neurons in their cerebral cortex than cats, a sign they are more capable of thinking, planning and other complex behaviours.

LOVE AT FIRST SIGHT DOESN'T EXIST

Sorry, Cupid, the feeling of 'love at first sight' is a combination of a strong initial attraction and a tendency to project current feelings into the past, a study at the University of Groningen in the Netherlands has found.

ORANGUTANS USE PAINKILLERS

A team at the University of Exeter watched Bornean orangutans chewing leaves from the *Dracaena cantleyi* plant and spreading the resulting lather onto their arms. The plant tastes bitter but has anti-inflammatory qualities, so it's likely the apes are using it to soothe their skin, the researchers say.

PALAEONTOLOGY

TICK GRASPING A DINOSAUR FEATHER DISCOVERED PRESERVED IN AMBER

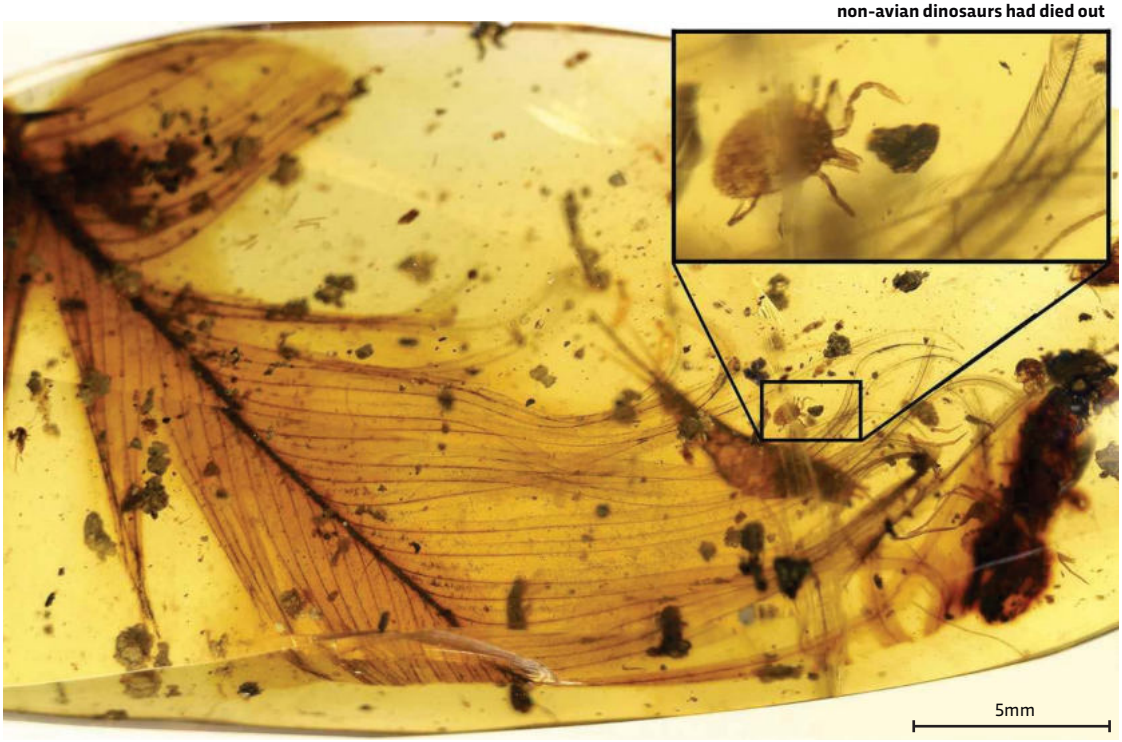
This incredible photograph shows a tick clutching onto a 99-million-year-old dinosaur feather perfectly preserved in a chunk of Burmese amber.

The sample was found in a collection owned by the Oxford University Museum of Natural History and dates back to the Cretaceous period which ran from 145 to 66 million years ago. The feather is similar in structure to that of modern-day birds and offers the first direct evidence of an early parasite-host relationship between ticks and feathered dinosaurs.

"The fossil record tells us that feathers like the one we have studied were already present on a wide range of theropod dinosaurs, a group which included ground-running forms without flying ability, as well as bird-like dinosaurs capable of powered flight," said lead researcher Dr Ricardo Pérez-de la Fuente. "So although we can't be sure what kind of dinosaur the tick was feeding on, the mid-Cretaceous age of the Burmese amber confirms that the feather certainly did not belong to a modern bird, as these appeared much later in theropod evolution according to current fossil and molecular evidence."

Unfortunately, researchers will not be able to extract a sample of dinosaur-building DNA, *Jurassic Park*-style, from the tick and feather, but such findings can help to shed light onto the everyday lives of dinosaurs.

Ticks continued to thrive, even when non-avian dinosaurs had died out



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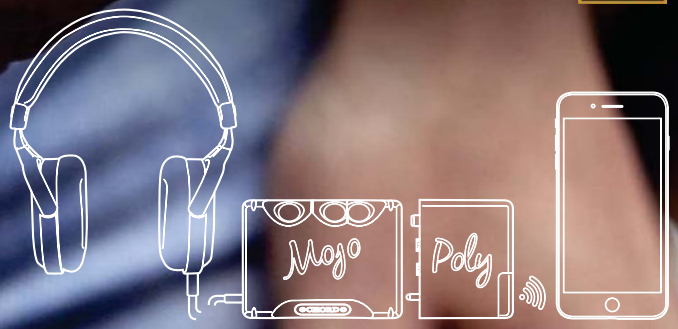

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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

JANUARY 2018 EDITED BY RUSSELL DEEKS

GREEN RIDE

In December, the first battery-powered black cabs hit the streets of London, just a few weeks after the news broke that all newly licensed London taxis will need to be zero emissions from January 2018.

The TX taxis, which use Volvo technology, are something of a hybrid system. They can travel 130km (80 miles) on a charge and are fitted with a 1.5-litre petrol engine for longer journeys. They're crammed with tech too, and come complete with contactless card machines, Wi-Fi, power sockets and USB charging capabilities, while their filter system will scour gases and particulates from the air. It is hoped that the new cabs, which cost £55,000 to buy, will help improve conditions in the pollution-filled capital. By 2021, there should be over 9,000 of these cabs operating in London – look out for them on your next trip!

WANTED

1 BUZZ OFF

This new offering from LG is available in India and comes with a detachable mosquito repeller that LG claims will keep the pesky insects at bay. It uses ultrasonic soundwaves, which are inaudible to the human ear.

LG K7i: Mosquito Away
₹7,990 (£92 approx), lg.com

2 MIRRORLESS MARVEL

Panasonic's new flagship mirrorless camera features a 20.3MP sensor and an autofocus speed of 0.04s. It will auto-stitch consecutive pics together to create high-res 80MP images, and shoots 4K video too.

Panasonic Lumix G9
£1,499 (body only), panasonic.com

3 SPOTIFY SHUFFLER

This tiny music player is billed as 'an iPod Shuffle for Spotify'. It lets you download up to 1,000 tracks from the streaming service, then play them back wherever you are – with no need for your phone, or even a wireless signal.

Spotify Mighty
$85.99 (£65 approx), bemighty.com

4 SADDLE UP

This folding electric bike has a range of 80km in pedal-assist mode or 50km without pedalling, and boasts a top speed of 32km/h. But the real news is the price: it's just £370, which is £130 less than its nearest rival.

Jolt Electric Bike
$499 (£370 approx), joltelectricbike.com

5 TUNES TO GO

This new model of Minirig speaker is the tiniest yet. At just 84x53mm, the Minirig Mini will slip into your pocket, yet will pump out 15W of sound for up to 30 hours. It can also connect to the Minirig Subwoofer if you want more bass.

Minirig Mini
£99.95, minirigs.co.uk

6 SLEEP EASY

These drown out the noise that's keeping you awake, whether it's a snoring partner or mad seagulls that's to blame. They use 'soothing' sounds to draw your attention away from disruptive noise and can work as an alarm-for-one too.

Bose noise-masking sleepbuds
Price TBC, bose.com

6

BIONICS

FORD WORKERS ARE BEING GIVEN EXOSKELETONS

The EksoVest reduces the strain experienced from repetitive overhead work, to keep Ford employees healthier

Workers at two Ford plants in the US are being issued with upper-body exoskeletal devices to take the strain out of lifting and overhead tasks.

The EksoVest is the brainchild of a California-based company called Ekso Bionics. The non-powered device can be worn by those standing 1.65-1.98m (5ft 5in-6ft 6in) tall, and provides 3-6kg of adjustable lift assistance to each arm. But it's not really built with heavy lifting in mind – most of that is taken care of by robots in today's car plants. Rather, it's designed to support the spine and shoulders when working overhead (as car manufacturers regularly need to do, for instance when assembling an automobile's chassis, exhaust system or axles), reducing both the amount of injuries that occur and the amount of muscular fatigue that the workers experience.

Ekso Bionics co-founder Russ Angold said: "Collaboratively working with Ford enabled us to test and refine early prototypes of the EksoVest based on insights directly from their production line workers. The end result is a wearable tool that reduces the strain on a worker's body, reducing the likelihood of injury and helping them feel better at the end of the day, increasing both productivity and morale."

The device has been rolled out to the workforce with the support of the United Automobile Workers union, and if the trials in the US go well, Ford plans to extend the trial to plants in Europe and South America.

HEALTH

THIS NERVE STIMULATOR CAN HELP HEROIN ADDICTS RECOVER

The US Food and Drug Administration (FDA) has just approved a "percutaneous nerve field simulator" for use in treating those addicted to heroin and other opioid drugs.

The United States is currently in the grip of an opioid addiction epidemic, caused largely by over-prescription of painkillers such as Oxycontin and Vicodin. As a result, drug overdoses are now the leading cause of death among under-50s in the US, having overtaken car accidents and shootings. One reason this problem has proven so intractable is that for those addicted to opiates, withdrawal symptoms can be crippling.

The NSS-2 Bridge from Innovative Health Solutions is designed to make coming off such drugs easier, by vastly reducing those symptoms. The electrical nerve stimulator is placed behind the patient's ear, and contains a battery-powered chip that emits electrical pulses to stimulate branches of certain cranial nerves via diodes that attach to the skin. These pulses are said to offer relief from withdrawal symptoms such as sweating, gastrointestinal upset, agitation, insomnia and joint pain. The device, which will only be available on prescription, can be worn for up to five days, which is about how long acute physical symptoms of withdrawal usually last. FDA commissioner Dr Scott Gottlieb said: "The FDA is committed to supporting the development of novel treatments, both drugs and devices, that can be used to address opioid dependence or addiction, as well as new, non-addictive treatments for pain that can serve as alternatives to opioids."

The NSS-2 Bridge stimulates nerves to reduce symptoms of opioid withdrawal

PHOTOS: FORD, INNOVATIVE HEALTH SOLUTIONS

HEALTH

AUGMENTED REALITY GLASSES TO HELP THE SIGHT-IMPAIRED

A start-up based at the University of Oxford has developed augmented reality glasses that can help the visually impaired to see.

OxSight's glasses can't do anything to help people who are completely blind, but the totally blind are only a small fraction of the visually impaired community. The glasses can, on the other hand, help those who suffer from a wide range of conditions such as glaucoma, retinitis pigmentosa or diabetes-related sight loss. They work, essentially, like glasses on steroids, using front-mounted cameras to see what's in front of the wearer and then overlaying a computer-enhanced version of the resulting image onto the lenses. Depending on the wearer's specific condition, they can enhance colours, sharpen up the image so that it looks 'normal' when seen by someone with blurred vision, or create a simplified, 'cartoon' version of reality that's visible even to those with severely reduced vision. The glasses were developed by OxSight in association with Royal National Institute for the Blind and the Royal Academy of Engineering, and with the assistance of £500,000 prize money from the 2015 Google Global Impact awards. They pair with a smartphone, which is where all the intensive graphics processing goes on. This means the glasses require little onboard computing power.

Feedback from early users has been extremely positive, says OxSight, and the company hopes to bring the product fully to market very soon. In the meantime, they are looking for more 'guinea pigs' – so if you suffer from impaired vision and want to give the specs a try, see **smartspecs.co** for details.

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MISSION INTO THE SUN

We've visited Pluto and the outer reaches of the Solar System, and our rovers are trundling over the surface of Mars. Yet the Sun has remained stubbornly out of reach… until now

WORDS: DR STUART CLARK

This summer, NASA will launch one of its most ambitious space missions to date: the Parker Solar Probe. Travelling at a blistering 720,000km/h (450,000mph), the spacecraft will repeatedly dive closer to the Sun than any previous spacecraft in history. It will venture so close that the Parker Solar Probe team refers to it as touching the

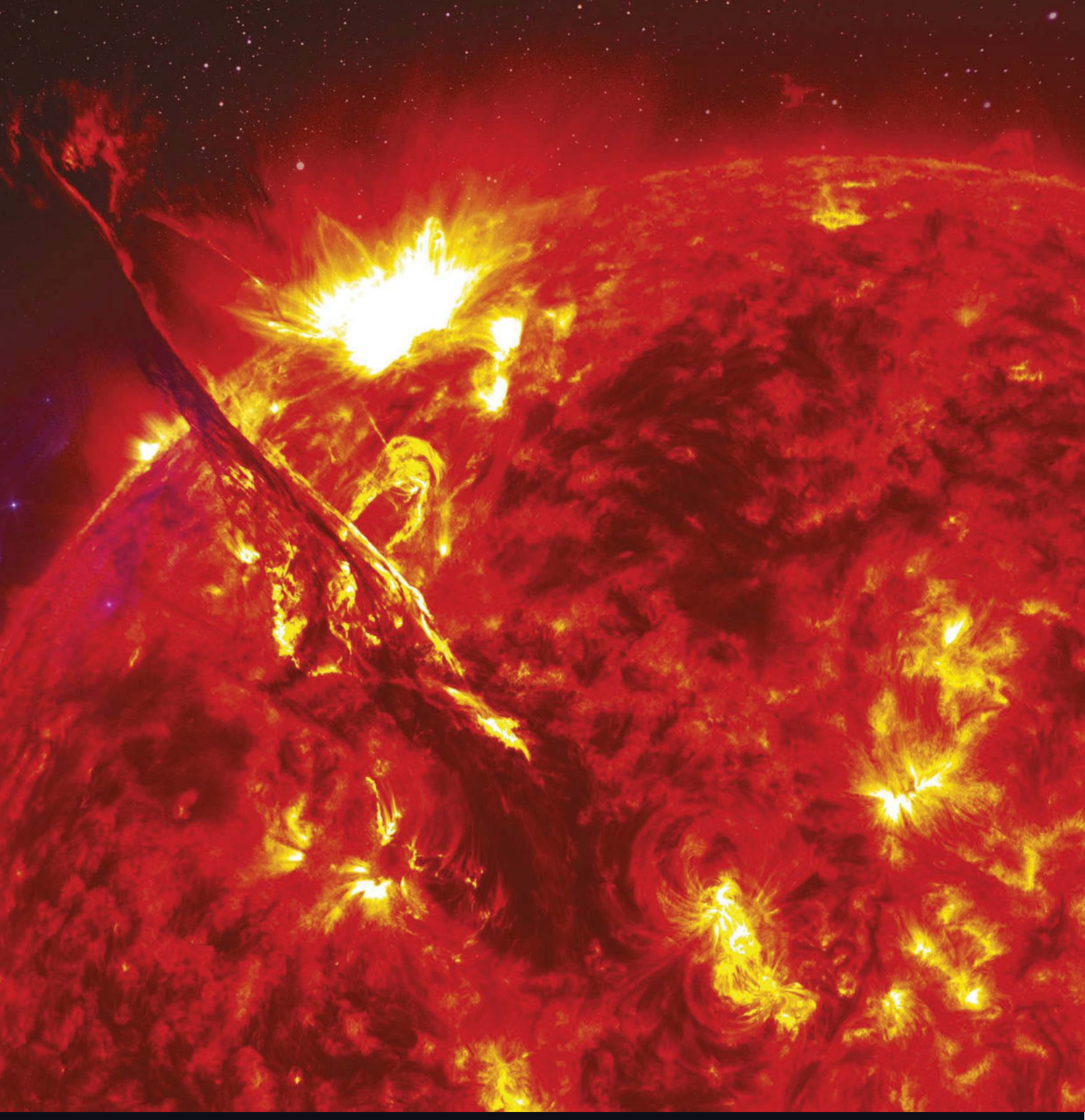


ILLUSTRATION: ANDY POTTS

Sun. In fact, it will dive in and out of the Sun's atmosphere, known as its corona. And it's not going to be alone up there.

In February 2019, the European Space Agency (ESA) will launch a solar mission of its own, called Solar Orbiter. This craft will not go as close to the Sun as its NASA counterpart but it will still be bathed in intense sunlight, almost 500 times that experienced by a spacecraft in Earth's orbit. Unlike Parker ▶

"Travelling at a blistering 720,000km/h, the spacecraft will repeatedly dive closer to the Sun"

Solar Probe, which spends only a short amount of time in the fierce heat as it dives in and out, Solar Orbiter will stay put for years, watching and measuring the Sun.

Both of these missions have a single goal: to find out more about the way electrified gas known as plasma is launched from the Sun's atmosphere out into space. This continuous stream is known as the solar wind. It carries energy and the Sun's magnetic field through space, and understanding it could solve a problem that's been mystifying scientists for decades and could be the key to safeguarding our technological society.

WHAT A WIND

When the solar wind collides with Earth, it can disrupt or even destroy electrical technology in orbit and on the ground. One recent study by the US National Academy of Sciences found that without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone, and it would not be quick to fix. The report found that such an enormous solar flare could cause so much damage to power stations that the US eastern seaboard could be left without power for a year. Europe is similarly vulnerable. Yet while something of this magnitude would only happen once every couple of hundred years, smaller storms happen more frequently. Most of these cause little disruption, but all have an effect. In March 1989, for example, a small solar storm severely damaged a power transformer on the Hydro-Québec power system. It took down their power grid for more than nine hours as emergency repairs were carried out. And more recently, in 2003, a series of solar storms that took place around the Halloween period caused more than half of NASA's satellites to malfunction in some way, while aeroplanes had to be re-routed away from polar latitudes because of the large amounts of radiation associated with the intense aurora.

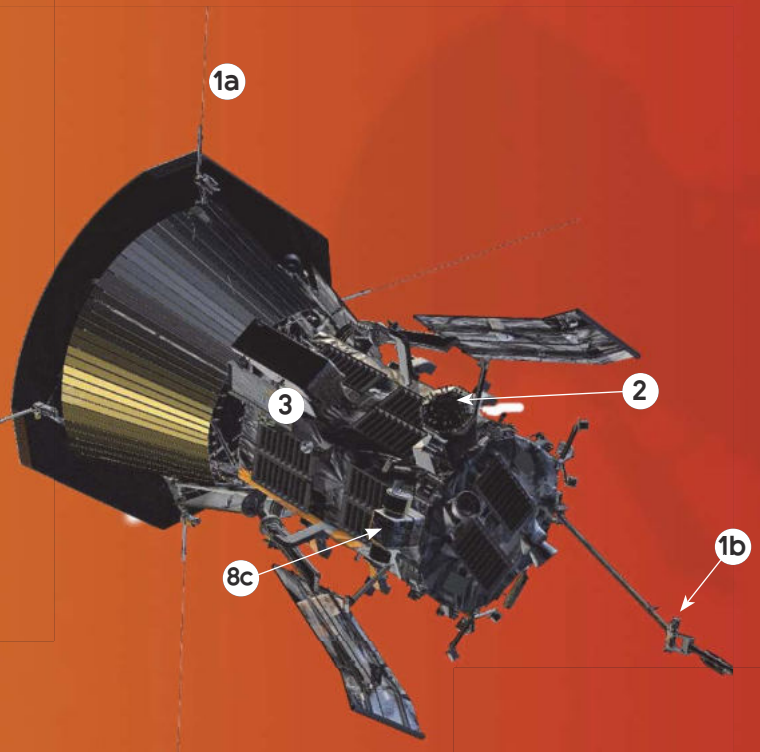
ABOVE: **The solar array of the Parker Solar Probe undergoing thermal tests**

"Without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone"

So while studying the Sun has never been more timely, the desire to do so stretches back before the space age to the 19th Century, when a solar mystery was uncovered. On 7 August 1869, astronomers gathered across Russia and North America to observe a total solar eclipse. In those fleeting minutes of darkness, the scientists got to see something not visible at any other time: the ghostly veils of the solar corona, the Sun's outer atmosphere. It was an object of fascination for the astronomers of the day. Two of the astronomers, Charles Augustus Young and William Harkness, were using spectroscopes to split the coronal light into its constituent wavelengths. They knew that the various chemical elements gave out light at specific wavelengths, and by measuring these 'spectral lines' they would be able to establish the chemical components of the corona. Working independently, they both discovered a green spectral line with a wavelength of 530.3nm. It caused great excitement at the time because there was no known chemical related to this wavelength, so the astronomers thought they had discovered a new element. They named it coronium.

It turned out that Young and Harkness were wrong, yet it wasn't until the 1930s that scientists understood

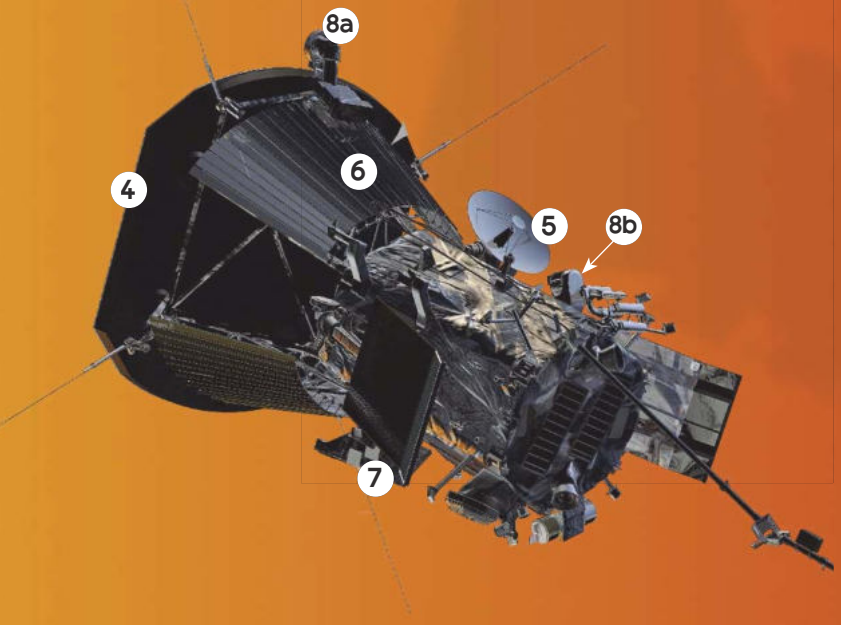
PARKER SOLAR PROBE DIAGRAM



1 FIELDS EXPERIMENT (FIELDS)
Will make direct measurements of electric and magnetic fields and waves in the solar wind, and of density fluctuations and radio emissions.

2 INTEGRATED SCIENCE INVESTIGATION OF THE SUN (IS☉IS)
Observes highly accelerated electrons, protons and heavier particles, and correlates them with solar wind and coronal structures.

3 WIDE-FIELD IMAGER FOR SOLAR PROBE (WISPR)
Provides images of the solar wind, shocks and other plasma structures as they approach and pass the spacecraft.



4 THERMAL PROTECTION SYSTEM (TPS)
An 11.43cm-thick carbon-composite shield that will withstand temperatures outside the spacecraft that reach nearly 1,377 °C.

5 HIGH GAIN ANTENNA
Used to communicate with Earth. The downlink data rate when close to the Sun will be around 167kb/s. Not much compared to modern broadband speeds.

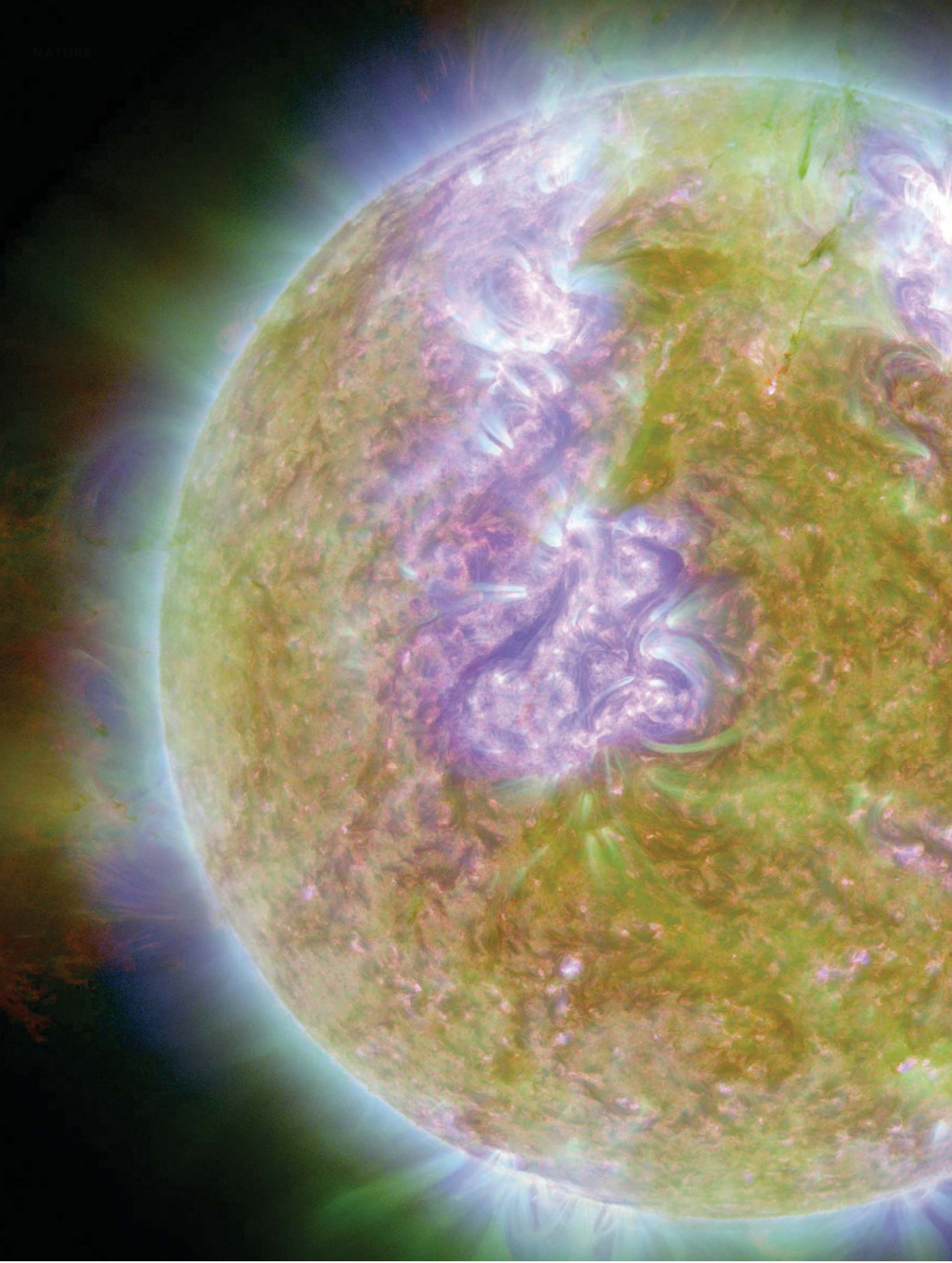
6 SOLAR ARRAY COOLING SYSTEM
Operating in 475 times the solar intensity experience in Earth orbit, the solar arrays are cooled by a 4m² radiator that sheds waste heat into space.

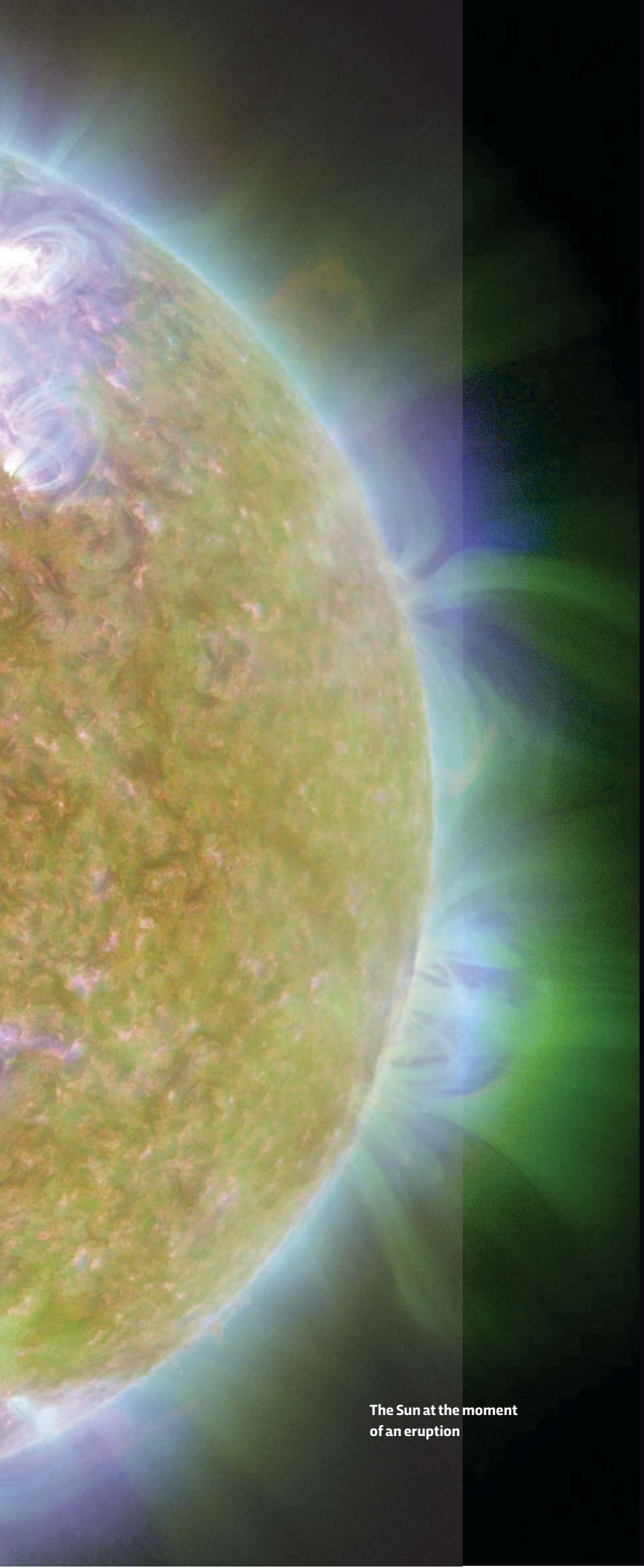
7 SOLAR ARRAYS
Although just 1.55m² in area, the solar arrays generate 388W of electrical power at closest approach to the Sun.

8 SOLAR WIND ELECTRONS ALPHAS AND PROTONS (SWEAP) INVESTIGATION
Counts the most abundant particles in the solar wind and measures their properties such as velocity, density, and temperature.

why. Astrophysicists Walter Grotrian and Bengt Edlén conducted laboratory experiments and found that iron could give out that green light, but only if it were heated to an extraordinarily hot 3,000,000°C, turning it into an electrically changed gas known as a plasma. With this realisation the real mystery was born. What exactly is heating the Sun's corona to 3,000,000°C? The magnitude of the problem is enormous because the surface of the Sun is a mere (astronomically speaking) 6,000°C. "It defies the laws of physics and nature. It's like water flowing up hill. You move away from a heat source and it should get cooler not hotter," says Nicola Fox, mission project scientist at the Johns Hopkins University Applied Physics Laboratory. "What happens in this region that suddenly accelerates all of this coronal material to temperatures exceeding 3,000,000°C? It is mystery number one," says Fox.

And if that wasn't a big enough conundrum, there is a second, related mystery. The gas breaks away from the Sun just where the temperature peaks. "If you think of the Sun as a giant gravitating star, ▶





The Sun at the moment of an eruption

PHOTO: NASA/SOHO

it is going to hang onto its material. And yet the plasma is able to break away and move out and bathe all of the planets," says Fox.

This is the solar wind. It is made mostly of hydrogen and helium. The iron that betrayed the corona's great temperature actually makes up just a tiny fraction of its composition. The solar wind carries with it the Sun's magnetic field and streams out into space at about 1,600,000km/h (1,000,000mph). It bathes the planets, and when it collides with the Earth, it sparks the stunning auroras that shine in the polar skies.

STAY COOL

Astronomers say that the acceleration of the solar wind occurs at about 10 solar radii (one solar radius is equal to the radius of the Sun). "That's where Parker Solar Probe is going, it's a scientifically important region of space," says Imperial College London's Prof Tim Horbury, who is a co-investigator on Parker Solar Probe's FIELDS instrument.

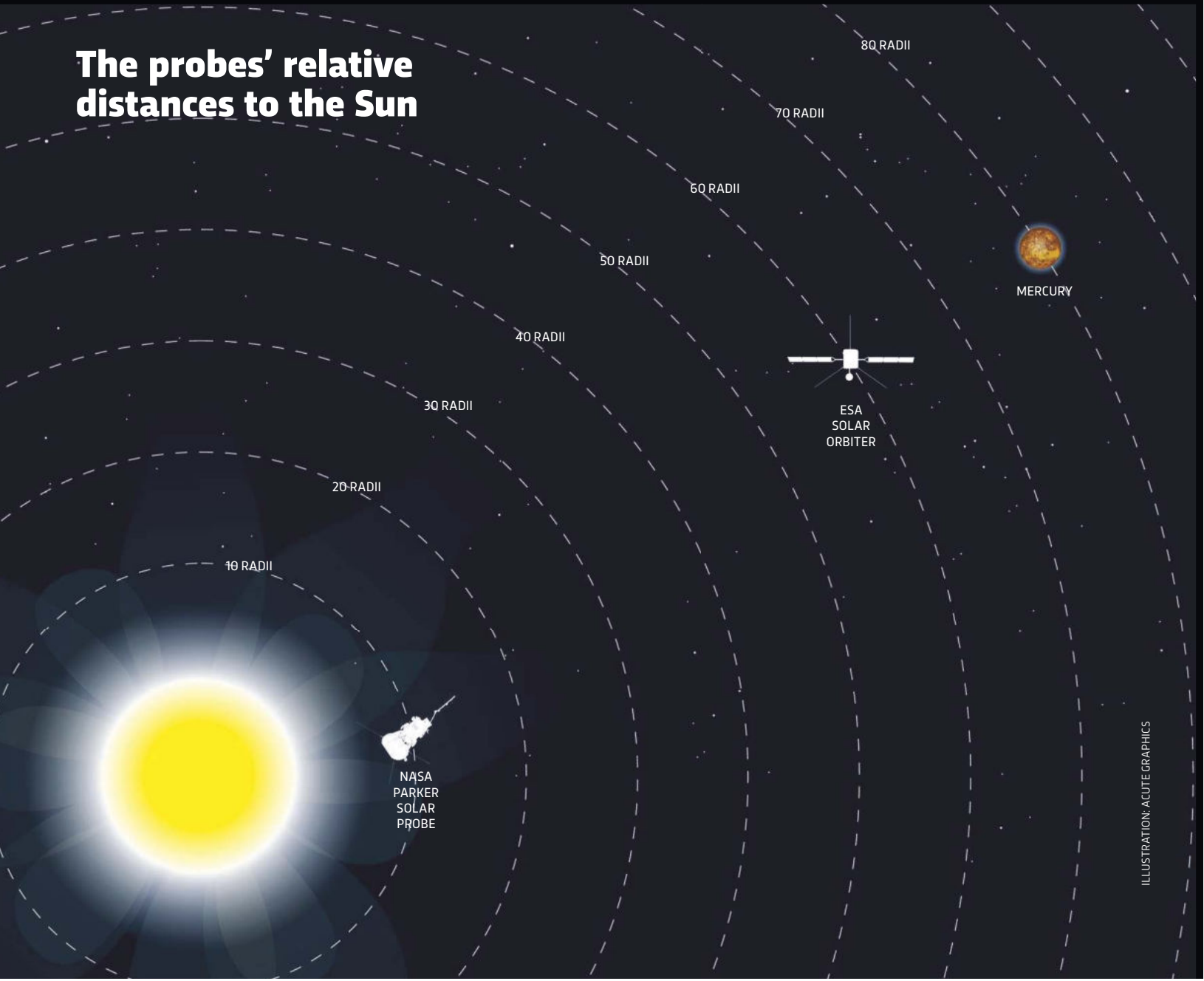
Through its series of extraordinarily close encounters with the Sun, Parker Solar Probe will repeatedly explore this key region. It will survive its plunge thanks to an innovative thermal protection system (TPS). This heat shield is made of two plates separated by a layer of carbon foam. The layer that faces the Sun is white and reflective. The foam itself is diffuse and light, and is composed of 97 per cent air. It was developed and manufactured especially for the spacecraft and is one of the key technologies that has enabled the mission to take place. It is just over 11cm thick, and will be heated to around 1,377°C during its close solar passes. On the other side of the TPS, where the spacecraft is located, the design will almost completely dissipate the heat, reducing it to a comfortable room temperature of around 21°C.

Solar Orbiter's heat shield takes a different approach because it has to withstand lower but constant heating. Its maximum temperature is likely to be around 520°C, but it is not going to head out to the orbit of Venus to cool down, like the Parker Solar

"The solar wind bathes the planets, and when it collides with the Earth, it sparks stunning auroras"

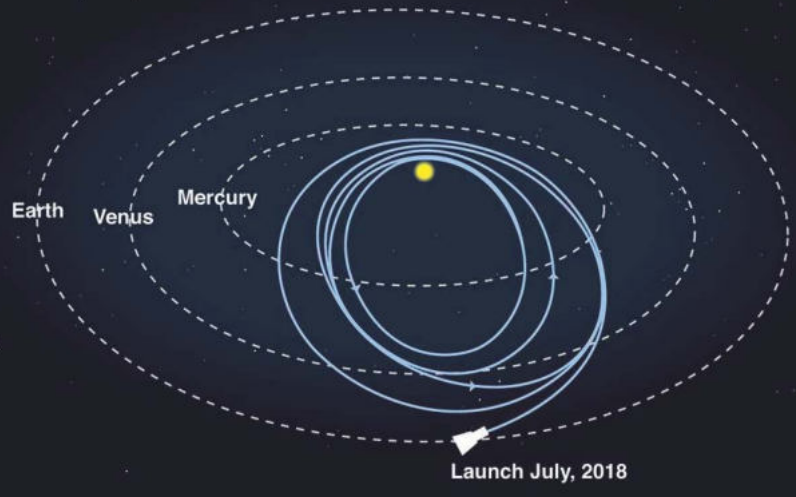
Probe. Solar Orbiter's heatshield is pitch black rather than white and reflective, as this means it will absorb heat and radiate it back out into space. It is made from titanium covered with a protective skin called SolarBlack, which is derived from a charcoal-based pigment made of burnt animal bones. This pigment is a type of black calcium phosphate and is widely used for fertiliser and metal alloy production, and for filtering heavy metals out of water. This skin keeps the European space probe safe so that it can operate continuously at a distance of 60 solar radii. Although this is six times further away than Parker Solar Probe's closest approach, there is a particular reason for choosing this distance. "It goes as close as you can go and still use telescopes to look at the Sun," explains Horbury. Parker Solar Probe's only telescope looks to the side to take images of the solar wind rushing by.

Solar Orbiter's telescopes will study the Sun's surface with a variety of instruments over a wide range of different wavelengths so that astronomers can determine the surface gas's densities, temperatures and the magnetic field. It then contains a second suite of instruments that measure the same properties for the solar wind as it passes the spacecraft. Parker Solar Probe is designed to fly through the exact region of the Sun's atmosphere where it breaks its connection to the solar surface and becomes the

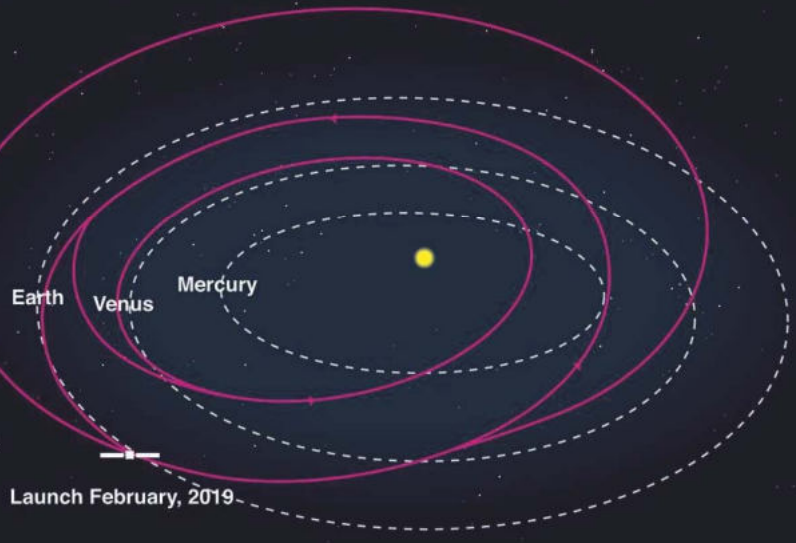


“The aurora was seen across two- thirds of the planet, the telegraph network went down and compasses spun uselessly”

Parker Solar Probe’s launch path



Solar Orbiter’s launch path



solar wind. So by sharing their data the mission scientists can make the connection between events on the solar surface, the launching of the solar wind, and the downstream conditions. This is the stuff of dreams for the people involved in understanding space weather.

“Solar Orbiter is all about making the connection between what happens on the Sun and what happens in the solar wind,” says Horbury.

EARLY WARNING

Beyond mere curiosity – which would be reason enough to launch these missions – there is an important practical application: safeguarding the technology we rely on every day.

As well as creating the aurora, the interaction of the solar wind with Earth’s magnetic field can be severely damaging to important technology. The Carrington Event, which took place in 1859, is the greatest of these so-called solar storms on record. The aurora was seen across two-thirds of the planet, the global telegraph network went down and compasses spun uselessly. Today, the same could happen with sat-navs, telecommunications and power stations – all the technology that society relies on to function. Yet we get only 30 to 60 minutes warning from a NASA spacecraft called ACE (Advanced Composition Explorer).

Once these two missions have performed their work, the hope is that this warning time will rise to a day or two. That’s because solar storms are sparked by flares on the Sun that trigger a sudden ejection of material from the corona into the solar wind. It takes a day or two for this eruption to cross space, so knowing the way in which the solar wind is launched is critical if we are going to calculate the severity of any incoming solar storms. It could also give us more time to prepare and protect any important electrics.

“The data we are supplying will be used to make transformational improvements to the models. A few years from now when we see a big event, the model is going to accurately tell us what is coming to the Earth,” says Fox. “It is extremely fortuitous that we have the two missions going up in a similar time frame. They are so synergetic, that I couldn’t be more excited that they will be up together. It’s perfect.” **F**

Dr Stuart Clark is an astronomy writer with a PhD in astrophysics. He is the author of *The Sun Kings* (£19.95, Princeton), which tells the story of the great solar storm of 1859.

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IS DRY JANUARY WORTH IT?

After an alcohol-infused festive season, many people stay off the booze in January. But can you really see any health benefits from just one month of sobriety?

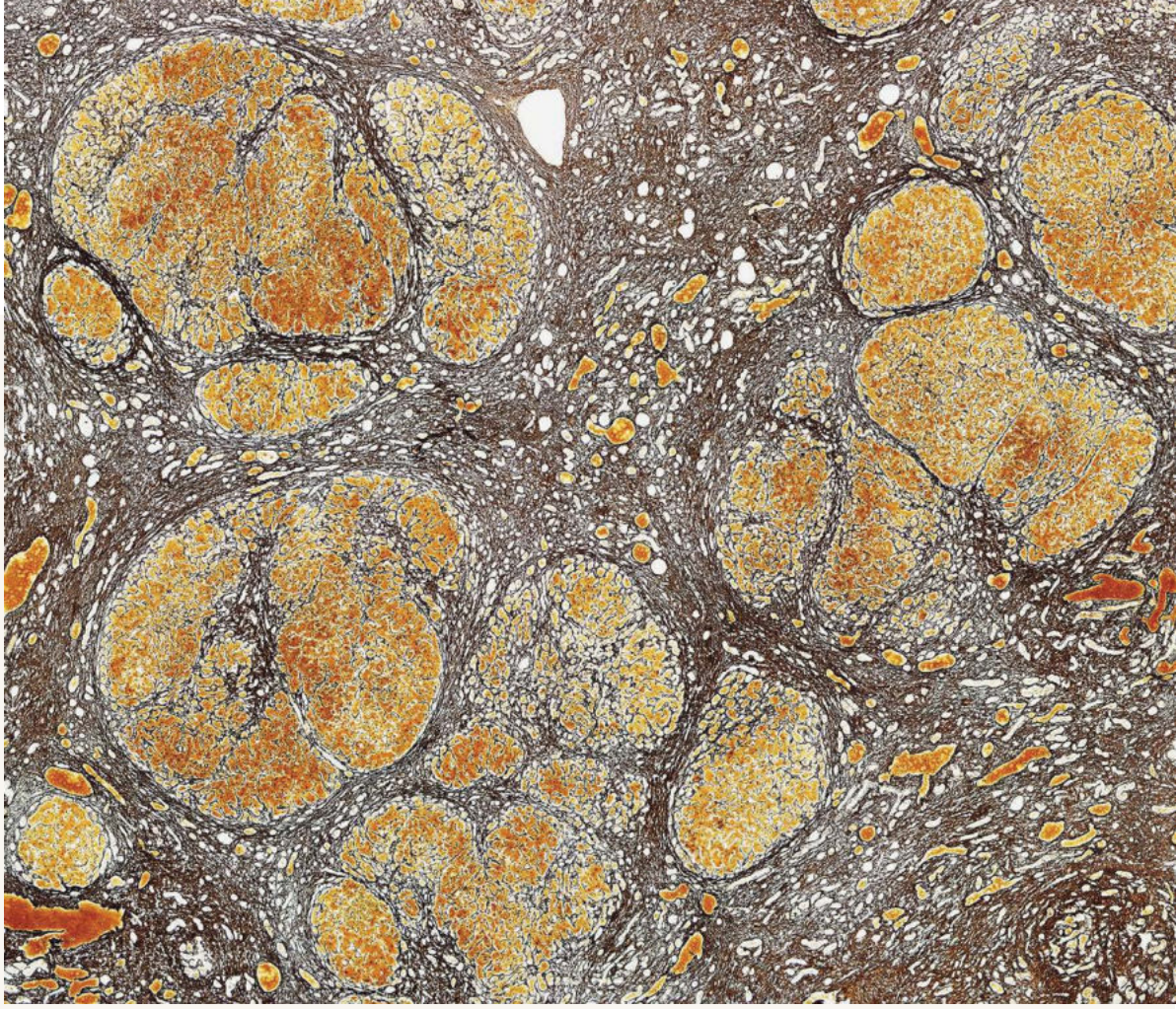
WORDS: DR MICHAEL MOSLEY

PHOTOGRAPHY: NICK BALLON. WITH SPECIAL THANKS TO THE HEREFORD ARMS KENSINGTON, LONDON

Choosing to do a 'Dry January' has become increasingly popular over the last few years and I've known quite a few people who have done it. Dry January is an idea being driven, among others, by a charity called Alcohol Concern. Alcohol Concern's website states that the reasons for doing a Dry January include: "enabling you to take control of your relationship with alcohol" and "driving a conversation about alcohol: why do we drink it, what does it do, and how can we reduce the harm it can cause?"

It says that the potential benefits include better sleep, improved skin, weight loss, having "an amazing sense of achievement at the end", and saving money (according to Alcohol Concern the average person spends £50,000 on booze in their lifetime).

This all sounds terrific. So when *BBC Focus* asked me if I fancied getting ahead of the game and giving 'Dry November' a go, I thought, "why not?". I enjoy a bit of self-experimenting and one of the advantages of doing it in November is that there are only 30 days in that particular month, so it would require one less ▶



day of total abstinence.

I am not and have never been a heavy drinker. Even at medical school, where there was a culture of heavy drinking among certain groups (mainly the rugby players), I hardly ever drank more than two or three pints in a single session. Once alcohol hits my brain I have about an hour of uninhibited fun before I go into a slump. Drinking does not make me good company. Nonetheless I have got into the habit of drinking most evenings, mainly red wine, so I thought it would be an interesting challenge.

I started off by logging everything I drank for a couple of weeks in the lead up to November, and it worked out at around 20 units a week. While this isn't a huge amount of booze, it is well over the current UK government guidelines of 14 units a week for men and women. The guidelines used to be 21 units a week for men, 14 for women, but they were changed in December 2016, when the Department of Health announced that, "there is no justification for drinking for health reasons".

I was surprised and somewhat sceptical about the definitive nature of this statement for reasons that I will come to in a moment, but it did give me further reasons to attempt an alcohol-free November. I went off and got some bloods taken, in order to measure my fasting glucose, liver enzymes and cholesterol levels, and I also weighed myself and measured my blood pressure. I put the bottles of wine out of sight and I was good to go.

ABOVE:
Microscope image of cirrhosis of the liver caused by drinking (left), compared to a healthy liver (right). The brown areas of the unhealthy liver are swathes of scar tissue; the orange areas are regions that have regenerated in response to damage

SOBER START

The first couple of weeks were challenging, because I had got into the habit of having a drink with my evening meal and I did miss it. I thought the best way to get through the month was to tell people what I was doing so it would be too embarrassing to backtrack.

"I found that I was better company when I went out in the evening because I was less likely to have a postprandial slump"

My friends were understanding, and it also meant that when we met for a drink I was no longer tempted to eat crisps at the bar. I found that I was better company when I went out in the evening because I was less likely to have a postprandial slump. I did not, however, notice much improvement in my sleep or any impressive changes in my skin.

It seemed that there were good reasons to stick to Dry November, but I wondered whether there would really be any lasting benefits if I kept it up. Is alcohol, at the relatively modest levels that I've been drinking it for the last few years, really that bad?

According to the Department of Health if you are drinking 14 units of alcohol a week, let alone the 20 units that I was averaging, then you are increasing your chance of dying by around 1 per cent. That figure sounds quite scary, but Sir David Spiegelhalter, Winton Professor of the Public Understanding of Risk, at Cambridge University, has crunched the numbers and put some context on the 1 per cent chance of dying claim.

"An hour of watching TV a day, or eating a bacon sandwich a couple of times a week, is more dangerous to your long-term health," he explains. "It all seems to come down to what pleasure you get from moderate drinking."

So not that scary after all. But what about the claim that moderate drinking is worse for you than total abstention and that "there is no justification

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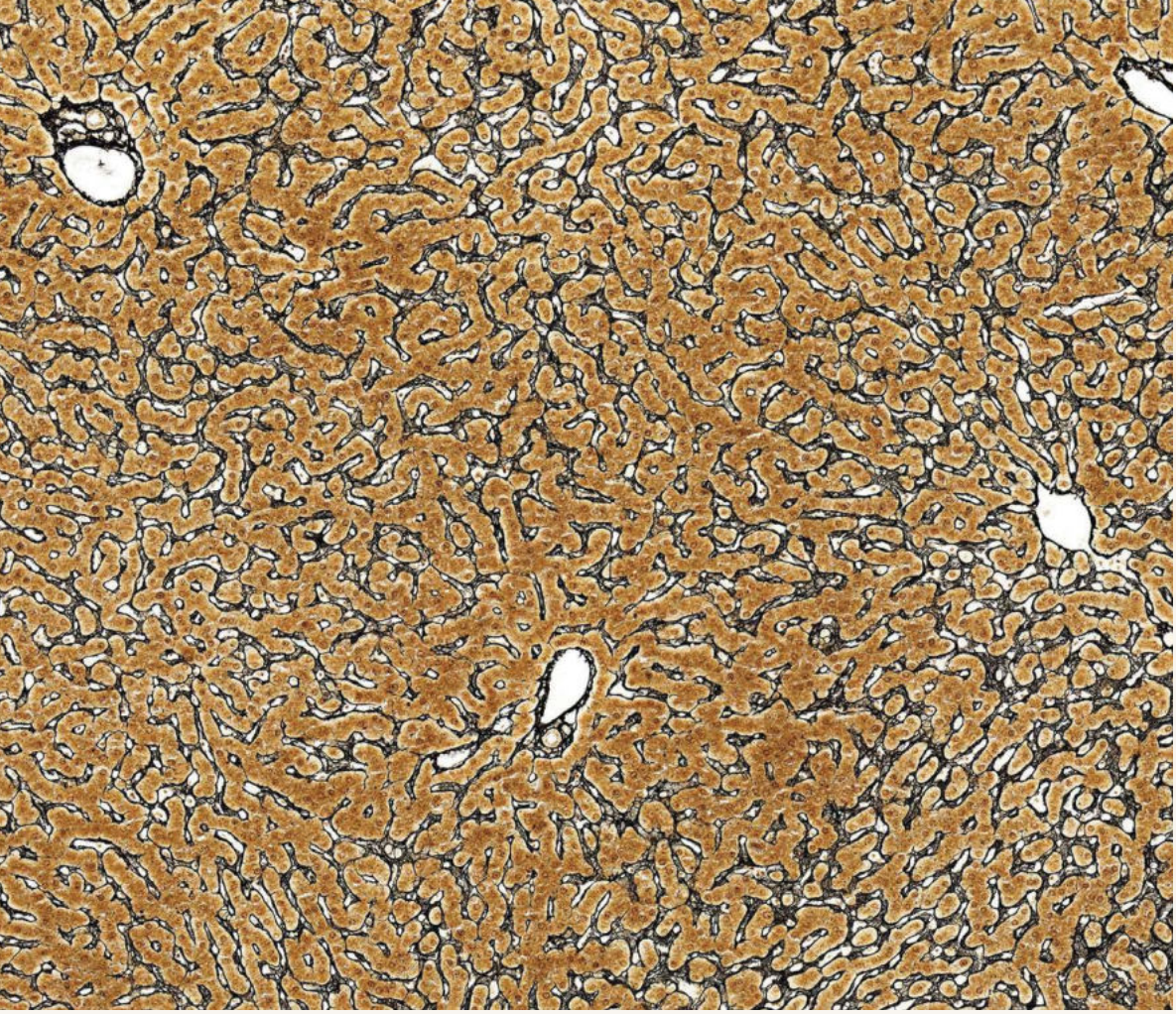


for drinking for health reasons". This is certainly the view of Prof Tim Stockwell, director of the Centre for Addiction Research at the University of Victoria in Canada. He has advised many governments, including our own, on alcohol guidelines and thinks there are no biochemical benefits to drinking. However, he does concede that moderate drinking can be sociable, and may be beneficial for us purely for those reasons.

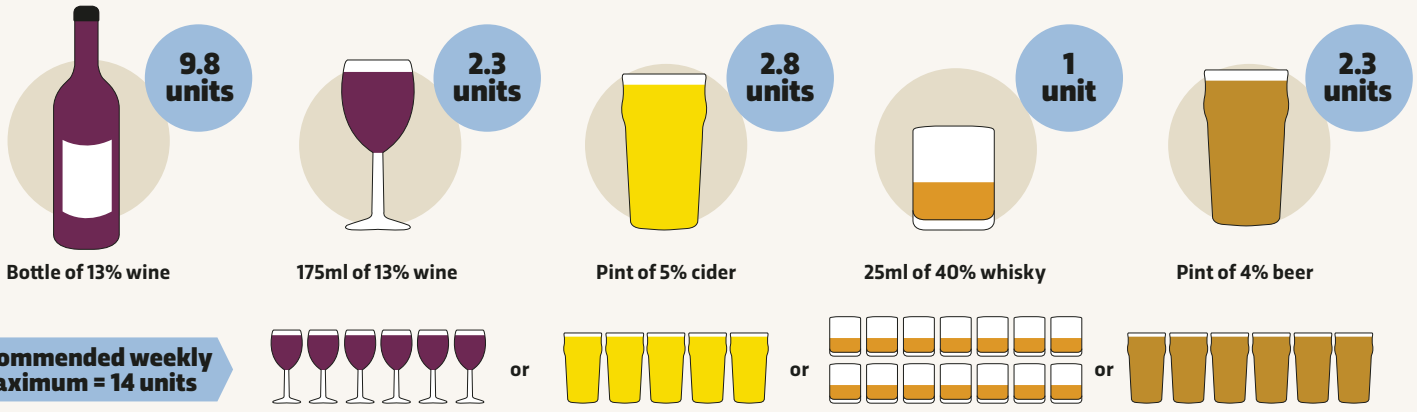
"There are 60 different ways at least that alcohol can make you unwell or kill you," he explains to me over a glass of water. "It's not just the obvious things like liver disease. A man drinking three to four units a day increases his risk of developing prostate cancer. Alcohol, at whatever level, raises a woman's risk of breast cancer. There'd be 10 per cent fewer deaths from breast cancer worldwide if there was no drinking."

Stockwell thinks the studies that suggest moderate drinking is protective are flawed. He says the problem is that the group of people who 'don't drink' often includes former alcoholics and people who are in poor health, and that skews the apparent benefits of moderate drinking. He recommends abstinent days, abstinent months, and if you actually don't miss the stuff, abstinent years.

Dr Alexander Jones, a consultant cardiologist and clinical scientist at University College London, agrees that alcohol raises your risk of a wide range of cancers. He believes, however, that there is evidence that alcohol can be beneficial for the heart, at least in relatively low doses.

"Heavy drinkers have a much higher risk of developing heart disease than non-drinkers," he says. "But there are large prospective studies which show that if you drink modest amounts of alcohol, up to say two units of alcohol a day, then you are less likely to develop coronary heart disease or stroke later on in life." ▶

HOW MANY UNITS ARE THERE IN MY DRINK?



ARE THERE POTENTIAL BENEFITS OF ALCOHOL?

The Mayo Clinic in the US cautiously endorses the claim that there are potential health benefits to modest alcohol consumption, including:

- **Reducing your risk of developing and dying from heart disease.**
- **Possibly reducing your risk of ischemic stroke. This is when the arteries to the brain become narrowed or blocked, causing severely reduced blood flow.**
- **Possibly reducing your risk of diabetes.**

There are many possible reasons for the benefits listed above, but I recently came across a novel explanation. It turns out that wine – and red wine in particular – has a positive effect on gut bacteria.

Evidence for this comes from a number of sources, including a small study published in *The American Journal Of Clinical Nutrition* in 2012. The researchers recruited 10 middle-aged men and, after an alcohol-free week, randomly allocated them to either drinking a large glass of red wine (270ml), red wine with the alcohol removed, or gin (100ml) each day with their evening meal. After 20 days they switched regimes. By the end, each volunteer had followed each of the three different approaches. Throughout this experiment blood and poo samples were taken on a regular basis.

Compared to when they were alcohol-free, when the volunteers were drinking red wine, and to a lesser extent de-alcoholised wine, there were significant drops in blood pressure, in C-reactive protein (CRP – a measure of inflammation) and in their triglyceride levels (the amount of fat circulating in the blood).

There was also a marked change in their gut bacteria, with a particular increase in *Bacteroidetes*, the type of bacteria associated with slimness. They also noticed a significant increase in *Bifidobacteria*, which are associated with lowering cholesterol. While more research needs to be carried out, it appears that a small amount of alcohol may promote helpful gut bacteria.

So who is right? The best way to assess the impact of moderate drinking would be to take a large group of non-drinkers and randomly allocate them to either drinking alcohol or water, then follow them for many years. Such a study would be almost impossible to do. But a study along more modest lines was published in 2015 in the *Annals Of Internal Medicine*. For this study, researchers at Ben-Gurion University in Israel took 224 type 2 diabetics who rarely drank and randomly allocated them to either a 150ml glass of red wine, white wine or mineral water with their evening meal, every evening, for two years. For context, 150ml of wine a night works out at roughly 14 units of alcohol a week. The wine and water were provided free of charge and the empty bottles collected afterwards to make sure they really were drinking regularly.

INTO THE DRINK

So what happened during my experiment? Well, as a red wine drinker who struggles with their blood sugar levels I was delighted to read that when it came to measurable health benefits the red wine drinkers came out on top, with the white wine drinkers a close second, followed by the mineral water drinkers.

The researchers concluded that red wine was found to be superior in improving overall metabolic profiles, mainly by modestly improving the lipid profile, by increasing good (HDL) cholesterol and apolipoprotein A1 (one of the major constituents of HDL cholesterol), while decreasing the ratio between total cholesterol and HDL cholesterol.

Prof Iris Shai, principal investigator of the trial, said that while the two types of wine contained roughly the same amount of alcohol, "the red wine had 7-fold higher levels of total phenols and 4- to 13-fold higher levels of specific resveratrol group compounds than the white wine".

The study found that drinking 14 units of alcohol a week did not have any measurable negative effects on blood pressure, liver function tests, or lead to increased fat gain. In fact, surprisingly enough, sleep quality significantly improved in both of the wine-drinking groups, compared with the water-drinking group. Interestingly, the people who got the biggest benefit (and the only ones who saw improved blood sugar control) were those whose livers broke down alcohol particularly slowly, meaning the alcohol hung around in their systems for longer. This suggests that although red wine contains beneficial compounds, alcohol also plays a role.

PHOTOGRAPHY: NICK BALLON. WITH SPECIAL THANKS TO THE HEREFORD ARMS KENSINGTON, LONDON

"At the end of the month I stepped on the scales and saw that I had lost just over two kilograms, which was a pleasant surprise"

This was a smallish study done for a relatively short period of time and with a particular group of people – type two diabetics. Therefore, the team was rightly keen to point out that it should be treated with caution. It adds, however, to what I think is compelling evidence that the occasional glass of wine is unlikely to do harm and may well do good.

So what effects did an alcohol-free month have on me? When I reached the end of November, I stepped on the scales and saw that I had lost just over two kilograms, which was a pleasant surprise. A bottle of red wine contains about 630 calories, so a month of not drinking had saved me consuming around 5,000 calories, which adds up to around 0.7kg of fat. I suspect eating fewer crisps also helped.

It is hard to estimate how much money I saved, because when I went out for a drink or a meal I still paid for my share of the alcohol. At home I may have saved around £40 on the bottles of wine I didn't buy.

As for my biochemistry, well along with the weight loss there was a slight fall in my blood pressure and a modest improvement in my fasting glucose and cholesterol levels. My liver enzymes were unchanged.

All in all it was an interesting experiment to try. As a consequence of my findings, I will attempt to reduce my drinking to 14 units a week, as that is where the sweet spot seems to lie. So good luck to anyone who is giving Dry January a go. I will be cheering you on from the sidelines.

Dr Michael Mosley is an award-winning science journalist, who presents BBC's *Trust Me, I'm A Doctor*. His latest book, *The Clever Guts Diet*, is out now (£8.99, Short Books).

Pick up the February issue of* BBC Focus *(on sale 7 February) to read the first of Michael Mosley's new monthly columns.

If you are concerned that you or a loved one has a problem with alcohol, please contact your GP or ring Drinkline (0300 123 1110) for confidential, free advice.

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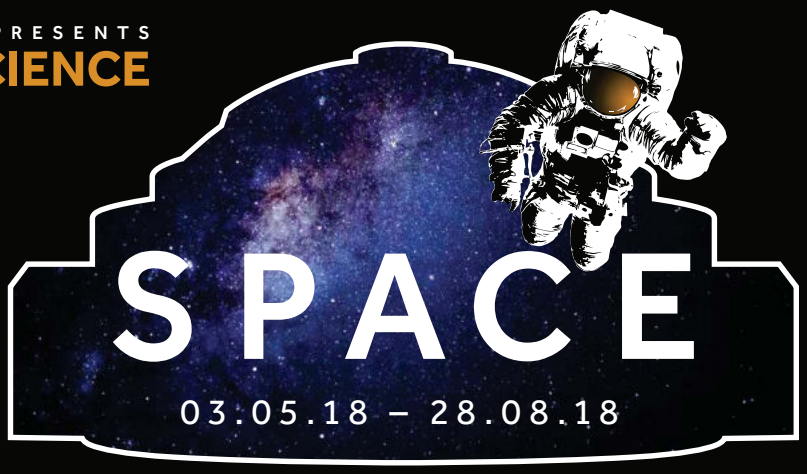

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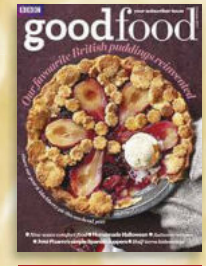
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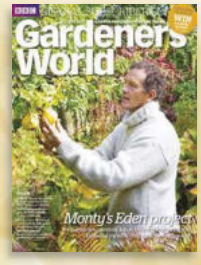
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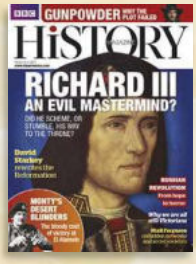
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THE SCIENCE OF FIGHTING FAT

Has Christmas taken its toll on your waistline? We navigate through the minefield of misinformation to find out what the experts really say about losing weight. Turn to page 56 for smart tips on how to shed that spare tyre

WORDS: **SIMON CROMPTON**

BBC ONE

Look out for a special obesity season on BBC One later this year. Check ***Radio Times*** for more details.

The statistics tell their own story. One in four people in England are now classified as obese, compared with one in six in the 1990s. Fifty-eight per cent of women and 68 per cent of men are now overweight.

Being overweight makes us less healthy: a new study published in *Lancet Public Health* shows a clear relationship between hospital admissions and body weight. But it also matters because being overweight makes many people unhappy.

A British Social Attitudes survey revealed that people who are overweight suffer significant stigma, and that 53 per cent of the British public are intolerant, believing that most overweight people could lose weight if they tried. But the science shows that it's not simply a matter of being weak-willed.

"There are very clear reward pathways for food in the brain, and so if something is rewarding and constantly available, why wouldn't you?" explains Prof Susan Jebb, a nutrition scientist at Oxford University. "In busy and stressed lives, you have to make a constant conscious effort to say no." Fortunately, science is now providing some answers on weight control. Just a decade ago, there weren't enough scientific diet trials to allow doctors and dietitians to provide evidence-backed advice. Now, there are clear scientific pointers on how to fight fat, and what the studies find may surprise you.

WHAT IS THE BEST DIET, ACCORDING TO SCIENCE?

When it comes down to it, the science of dieting is simple: eat less. You can do it with a low-fat diet (like the raw food diet), or a low-carb diet (like the Atkins or paleo diet). But the problem with diets is not so much losing weight, but finding a way to do it that is effective, safe, fits in with your lifestyle, and is sustainable so that your weight doesn't rocket up again.

Diet academics (as opposed to product pushers) avoid prescriptive advice because different diets fit different people's lifestyles and personalities. But recent research indicates that one particular group of diets is most effective for the greatest number of people. These are the supervised diet programmes, like the Cambridge Weight Plan, LighterLife and Optifast diets, consisting entirely of pre-prepared snack bars, shakes and other food products. You might assume these fast-acting diets would be condemned by scientists as drastic, unhealthy and gimmicky. Yet research is finding that these very low-calorie diets, also known as total food replacement diets, are effective and safe if applied correctly. A major analysis of trials last year, headed by Birmingham University's Centre for Obesity Research, showed that these diets brought an average weight loss of 10kg after 12 months. This compares with research showing that behavioural programmes (focused on changing eating habits and exercising), such as Slimming World and Weight Watchers, bring a weight loss of 4kg after one year.

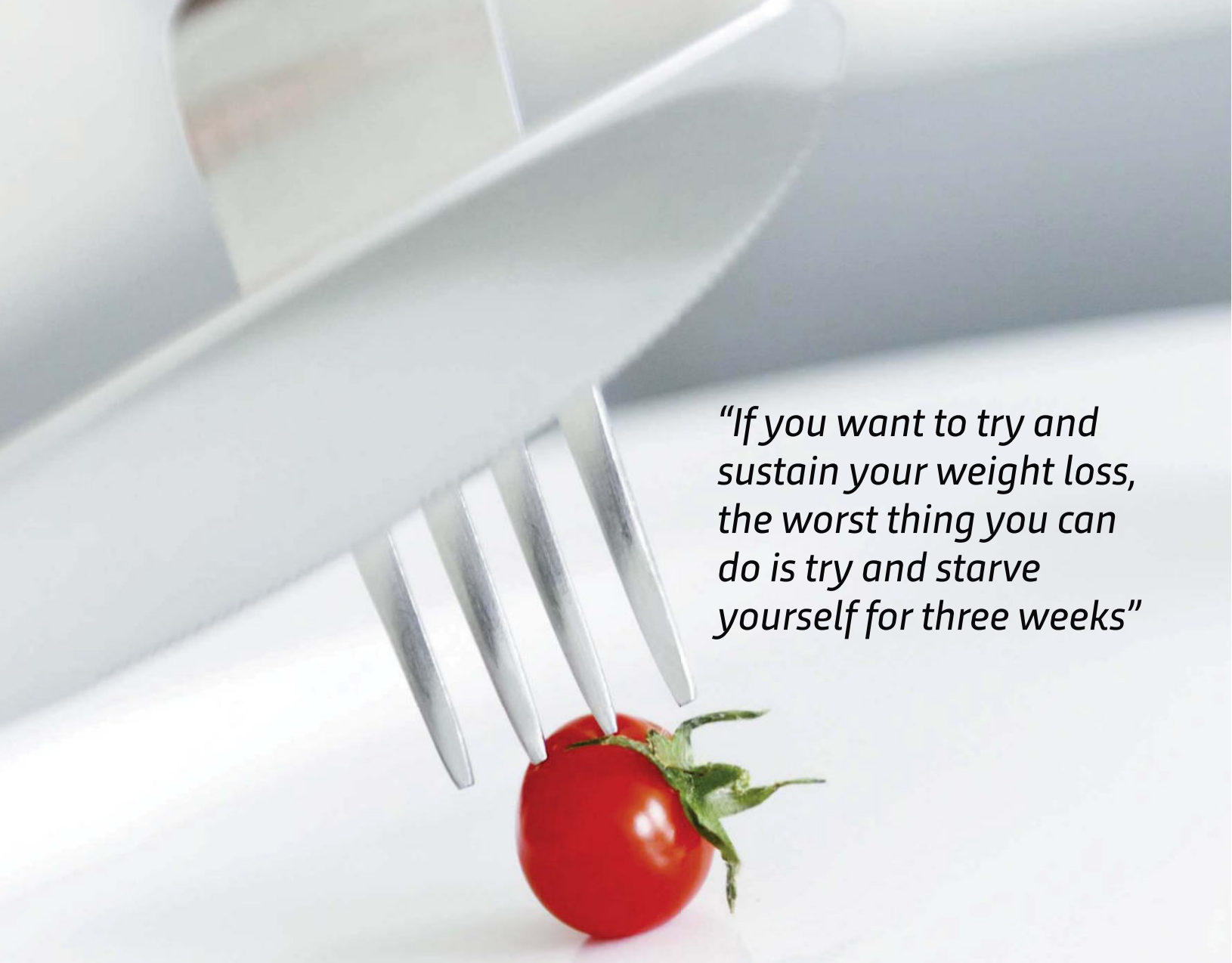
Jebb explains that, although research indicates that all dieters gain weight afterwards (no matter which regime you embark on), the more weight you lose the longer you stay beneath the 'obese and unhealthy' bar. "The research shows that the food replacement programmes which provide weekly or monthly behavioural support are associated with the best long-term success," she says.

And though food replacement diets may look extreme, they do contain a balance of nutrients that some do-it-yourself diets – for example, the milk diet or the lemonade diet – might not.

"Food replacement diets are easy, and if you want to lose weight, why not do it quickly? What's not to like?" Jebb says.

***Verdict:** Try a supervised diet programme to safely shed excess weight.*

PHOTO: GETTY



"If you want to try and sustain your weight loss, the worst thing you can do is try and starve yourself for three weeks"

DO CRASH DIETS WORK?

It depends what you mean by 'crash diet'. There is evidence that supervised food replacement diets work very well for many people. But what about the more DIY crash diets that claim to make your weight plummet? Diets like the cabbage soup diet, the grapefruit diet, and juicing and cleansing diets?

The evidence behind these is currently slim. However, there is less scientific opposition to losing weight quickly than there used to be. Australian research has indicated not only that more people achieve their weight loss goals if they lose weight fast, but also that losing weight quickly doesn't mean you'll regain it quickly as well. Rapid weight loss can motivate people to stick with some programmes, the researchers suggest.

But maintaining a healthy nutritional balance while on these diets can be a problem: advice from the NHS is still that "crash diets make you feel very unwell and unable to function properly... crash diets can lead to long-term poor health".

And both our biology and lifestyles may condemn many extreme crash diets to failure. Dr Giles Yeo, principal research associate at Cambridge University's Institute of Metabolic Science, specialises in the molecular mechanisms underlying the control of food intake and body weight.

"If you want to try and sustain your weight loss, the worst thing you can do is try and starve yourself for three weeks," he says. "Rather than taking a huge pendulum swing that will inevitably swing back in the other direction, I think people have to find some balance to lose weight long-term."

In particular, we have to address the fact that crash diets generally make us feel hungry. Yeo's research examines how the brain responds to hormones and nutrients that are released from the gut into the blood. These reflect the body's nutritional status, and the brain turns them into what we experience as 'fullness' or 'hunger'. You can find more advice for feeling fuller for longer at the end of this feature.

"One of the universal truths of weight loss is that if you want to eat less then you have to have a strategy to make you feel more full, otherwise you are simply fighting hunger for the rest of your life," Yeo says. "What we now know is that the longer something takes to be digested, the fuller it makes you feel – because as food goes down the gut, different hormones keep being released, most of which give us a feeling of fullness. That's why high-protein diets can work, because protein is more complex than fat or carbohydrate and goes further down the gut before it's broken into its constituents."

Look out for Dr Giles Yeo in the new series of *Trust Me, I'm A Doctor*, starting on BBC Two this January.

***Verdict:** Crash diets are not nutritionally balanced and will make you feel awful.*

DO INTERMITTENT FASTING DIETS WORK?

Intermittent fasting diets – for example, the Fast Diet and 5:2 diet – revolve around eating what you want some days a week, and then eating very little on the other days. They have become popular over the past five years. But are they more effective than other weight loss diets? The latest research suggests not.

A study published in an *American Medical Association* journal in 2017 found that, after a year, weight loss was not significantly different than for daily calorie-restricted diet groups.

Supporters of fasting diets claim they provide health benefits beyond weight loss. Indeed, animal studies have indicated that fasting prolongs life and reduces the risk of diabetes, cancer, heart disease and Alzheimer's disease. But human studies are scarce and contradictory.

A University of Southern California study of 71 adults published recently found that intermittent fasting reduced blood pressure and risk factors for cardiovascular disease, cancer and diabetes, and reduced body fat too. But another new study, from the University of Illinois, suggests it improves cardiovascular risk no more than any other diet.

What is undoubtedly true is that intermittent fasting diets suit many people because they don't disrupt lifestyles or family meals too much. "It's not particularly dangerous because you're essentially not changing what you're eating on most days, yet over a week you end up eating less," says Yeo. "They are very effective for some people."

***Verdict:** Intermittent fasting is no more effective than other calorie-restricted diets, but it works for many people as it isn't too disruptive.*

PHOTOS: GETTY X5

CAN YOU BE FAT AND FIT?

For decades, scientific debate has raged about the role of exercise in diet loss. Today, there is greater scientific consensus that food intake is more important than exercise for losing weight. But the debate goes on about whether being fit mitigates the health risks of being overweight.

Central to the controversy is research from the Cooper Institute for Preventive Medicine in Dallas, which shows that over-60s who exercise have lower mortality regardless of how much body weight they carry. American health psychologist Dr Traci Mann from the University of Minnesota is currently the most prominent figure in asserting that overweight people can live healthy lives as long as they exercise.

She says there is no evidence that overweight people have shorter lifespans, there is just evidence that people who are sedentary, poor and medically neglected (who are also often obese) live shorter lives. "Obesity only really leads to shorter lifespans at the very highest weights," she says.

There is no point in dieting, she claims. "To reduce your risk for cardiovascular disease and diabetes, you don't actually have to get thin, you just have to exercise."

But the 'fat but fit' camp has few supporters in the UK, and the theory has received a new setback from a recent study of 3.5 million GP records by the University of Birmingham. This found that 'healthy' obese people, who had normal blood pressure and cholesterol levels, were still at higher risk of serious disease than healthy people of normal weight. The obese people had 49 per cent increased risk of coronary heart disease, 7 per cent increased risk of stroke, and 96 per cent increased risk of heart failure.

***Verdict:** Obese people with healthy blood pressure and cholesterol still have an increased risk of heart problems and strokes.*

ARE ANTIBIOTICS MAKING US FAT?

The past five years have seen interest in the idea that our gut bacteria play a crucial role in regulating weight, and killing them off with antibiotics is causing obesity.

The most recent evidence is fascinating but inconclusive. Studies in prestigious medical journals have produced contrasting results. One found that three courses of antibiotics before the age of two was associated with increased risk of early childhood obesity, while the other found that exposure to antibiotics in the first six months of life was not associated with early childhood weight gain.

Yet recent research is indicating a link between gut fauna and our body mass index. People with higher levels of *Christensenellaceae* bacteria – one in 10 of us – appear less likely to put on weight than those with lower amounts. Scientists from King's College London have found that levels of this bacteria are partly genetically determined.

According to Yeo, who investigated the possibility of microbial transplants to cure obesity for a BBC programme, this new field is important and requires research. "But I have yet to see convincing evidence that there are lean bacteria and obese bacteria," he says.

***Verdict:** More research needs to be done, but our gut bacteria may affect how readily we put on weight.*

DO FAT-BURNING TABLETS WORK?

Dozens of 'metabolism-boosting' supplements – including ingredients such as caffeine, capsaicin, L-carnitine and green tea extract – claim to stimulate energy processing in the body, increasing the rate at which we burn calories. But there's little evidence that these products work, and most of their claims are not subject to scientific scrutiny because they are classed as food supplements rather than medicines.

Some studies have indicated that people burn more calories when they take caffeine but, according to the Mayo Clinic, this doesn't appear to have any significant effect on weight loss. There is little data on most other 'fat-busting' pill ingredients, although there is some evidence from small studies that capsaicin, which is found naturally in chillies, can promote loss of abdominal fat and make people feel fuller.

There is a constant stream of news stories about food types that can apparently provide a shortcut to weight loss by boosting metabolism, reducing fat levels or promoting healthy gut bacteria. Cayenne pepper, apples, cider vinegar and cinnamon have all been in the news recently. The problem is that most of these stories are based on small or isolated studies, often in rodents not humans. There may be something in them, but it's still very early days.

***Verdict:** There is no easy fix for burning fat. Sorry!*

Simon Crompton is a freelance writer and editor who specialises in science, health and social issues. He tweets from @Simoncrompton2

PHOTOS: GETTY X5

WHAT'S THE SKINNY?

TIPS TO HELP YOU FIGHT FAT

1 Eat slowly

Research presented at a recent American Heart Association meeting has found that eating quickly expands your waistline and increases heart disease risk. According to obesity expert Dr Giles Yeo, eating too quickly means you're not leaving enough time for your gut to release hormones signalling to the brain that you're full. So hunger continues and you keep on eating.

2 Avoid 'empty' calories

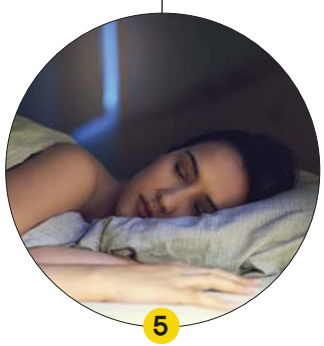
Empty calories are sugary foods that make you gain weight, but don't make you feel full. Fizzy drinks and fruit juices deliver large concentrations of sugar to the gut so quickly and easily that your intestines barely register it's hit them. Proteins and complex carbs, like beans, wholegrains, nuts and leafy vegetables, take longer to break down – so they're in your gut longer and produce lasting 'fullness' feelings.

3 Don't eat alone

Recent research published in a leading obesity journal found that men who eat alone at least twice a day increase their risk of developing obesity. The link seems to be less clear in women. This follows other studies indicating that loneliness can increase the likelihood of making unhealthy food choices.

4 Consider your crockery

Headline-grabbing studies have suggested that plate size, shape and colour, as well as cutlery size and weight, can affect how much you eat. Health experts continue to debate the merits of these findings. But there is little doubt that large portions contribute to weight gain, and an analysis in the *British Medical Journal* recommended smaller tableware.



5 Grab some sleep

More than 50 studies have looked into a possible link between sleep loss and weight gain, and recent reviews of the evidence have concluded that there is an association in both adults and children. Lack of sleep seems to disrupt the way we regulate hormones and metabolise glucose, and can cause increases in the hormone ghrelin, which stimulates appetite.

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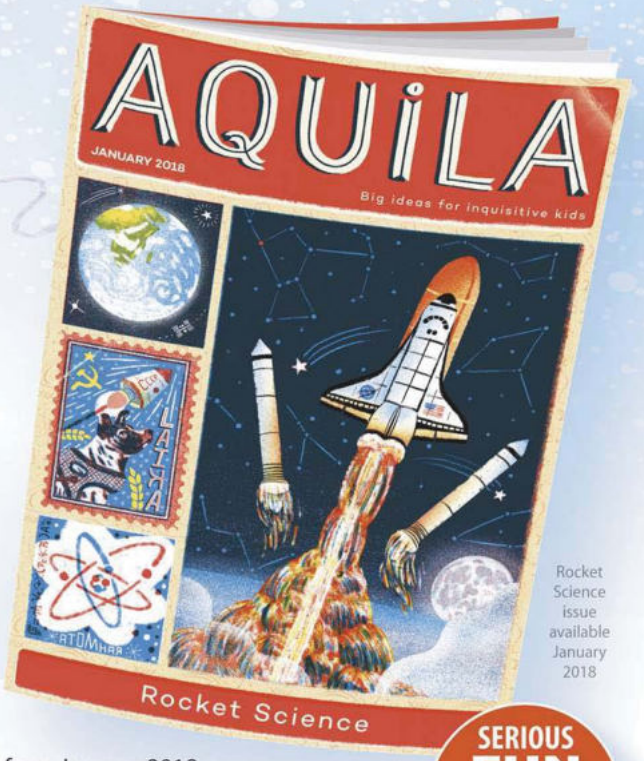

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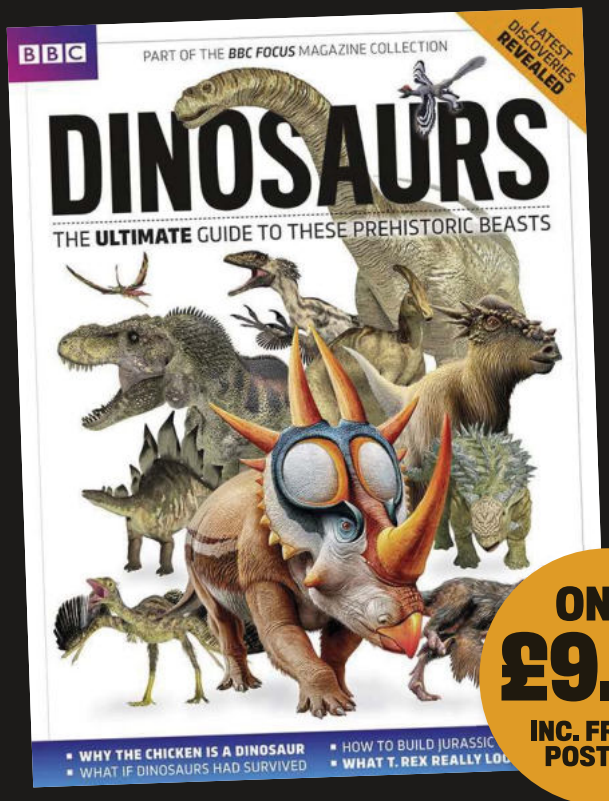

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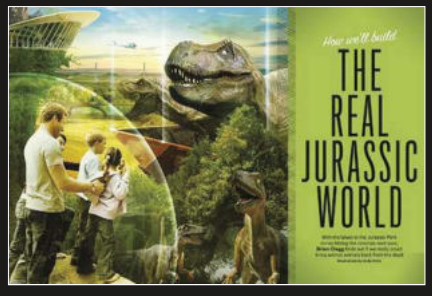

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IS IT TIME FOR A TECH DETOX?

Many individuals are hooked on their smartphones, and a growing number of people are entering rehab for technology addiction. So what could these extreme cases tell us about our relationships with gadgets?

WORDS: **EMMA YOUNG**

Can't put your phone down? You're not alone. A 2016 survey found that the average person spends 145 minutes a day on their phone – that's over 36 days a year. But for some, it's more than just a bad habit. Mental health hospitals that traditionally treated alcoholics and drug addicts are now treating tech addicts, too.

One such hospital is the Nightingale Hospital in London. Dr Richard Graham is head of its Technology Addiction Service, and the stories of his past and present patients* may sound familiar. Ryan is a teenager who spends 8 to 10 hours on screens after school, mostly on YouTube. Holly is obsessed with how many Instagram followers she has. Ollie, a man in his early-20s, suffered severe bullying in his teens, and became absorbed in gaming and Netflix. Recently, Ollie 'woke up' to what his world had become, Graham says, "and it was so upsetting for him. He felt he'd missed out on relationships, friendships, and all sorts of things that he could see now were what he'd really wanted." All this raises the question: when does a habit become a problem?

Technology addiction is a term that covers addiction to the use of electronic devices, especially smartphones and gaming consoles. Estimates of just how many people are affected vary between studies, from about 2 per cent to 6 per cent, depending on the country and age group. Either way, that equates to at least a million people in the UK alone. And with overuse of gadgets being linked to sleep deprivation, anxiety and depression, that's not good news.

'True' technology addiction, in which a person's brain shows the same kind of dependency on *League Of Legends* or checking their Instagram account as that of someone addicted to a drug like heroin, is clearly a big problem for the individuals affected. But it's rare, Graham says, to find someone who has a truly balanced relationship with technology, and ▶

PHOTO: ALAMY

*Names have been changed

"Checking messages via social media can become almost compulsive"

with their smartphone, in particular. "What about the rest of us," he says, "walking around, staring at our smartphones, narrowly escaping lamp posts and cars and not able to respond to the people in our lives, or not getting a good night's sleep." Even this level of tech use can interfere with our health, happiness and well-being, he says.

Nonetheless, many of us rely on technology for our jobs, and for staying in touch with friends and family. As Graham readily accepts, technology in the modern world is not only largely unavoidable but often extremely helpful. But in cases of what's termed life 'disruption' rather than 'addiction' – a broader category that surely many of us fall into – strategies designed to help people with technology addiction could help us to use our devices in a healthier way. It's not just addicts who could benefit from a tech detox.

A MODERN AFFLICTION

To understand how devices can get such a grip on us, it's useful to look at research into full-blown addictions. Psychologist Prof Mark Griffiths, the director of the International Gaming Research Unit at Nottingham Trent University, is a pioneer of research in the area. After 20 years of study, he's come to the conclusion that 'internet addiction' and 'smartphone addiction' are really misnomers.

People who are addicted to online gaming, online gambling, online sex, or online shopping are not internet addicts, he argues, but rather gambling addicts, sex addicts or shopping addicts who are using the medium of the internet to engage in their addictive behaviour. For a gaming addict who plays on their smartphone, the structural changes in their brain's reward system that cause cravings are down to the playing of the game, rather than the use of a phone. Repeated exposure to a game (or any other addictive behaviour or drug) causes nerve cells in the nucleus accumbens and the prefrontal cortex, areas of the brain respectively involved in motivation and decision-making, to communicate in a way that links liking something with wanting it. In other words, we start to crave it.

Social networking is perhaps one of the few genuine or 'pure' types of 'internet addiction', because there is not an offline equivalent. But here, the addiction is to an app, and as such this kind of compulsion should be understood as 'social networking addiction', according to Griffiths.

ABOVE AND BELOW: **At the US-based reSTART residential programme, technology use is restricted, so residents are encouraged to take part in alternative activities. There's a huge chessboard for games in the sunshine, while plenty of reSTART's notebooks are on hand for scribbling down stories and essays**

PHOTOS: RESTART LIFE LLC X4

These distinctions are vital for designing treatments. In the US, Internet Gaming Disorder is now a recognised psychiatric disorder. One former patient on a US 'internet addiction' rehab programme called reSTART has described to *The Guardian* how he used to play video games for 14 or 15 hours a day, with Netflix on in the background. Any time there was a break in that, he would play a game on his phone or text an ex-girlfriend. Of the truly tech-addicted patients that Graham sees at the Nightingale Hospital, gaming is also a common problem.

For many of us, though, it's texting, Snapchat, Twitter, Facebook and other apps that can run on our smartphones, and are always with us, that pose a big problem. One recent survey of smartphone use among US college students, for example, found that 12 per cent identified as 'fanatics' and 7 per cent as 'addicts'. "Our smartphones have turned into tools that provide short, quick, immediate satisfaction," observed Isaac Vaghefi at Binghamton University, who led the study. "Over time this makes us acquire a desire for quick feedback and immediate satisfaction."

Checking messages via social media can become almost compulsive, because of 'Fear of Missing Out'. This describes the anxiety that an interesting or exciting event may be happening elsewhere online.

So in a world where many of us carry smartphones in our pockets, and rely on our devices to keep us connected with everyone else, how can we know if we have a problem in the first place?

If gaming, checking Twitter or watching Netflix are encroaching on more and more of your life, it's worth noting Graham's observation that heavy use

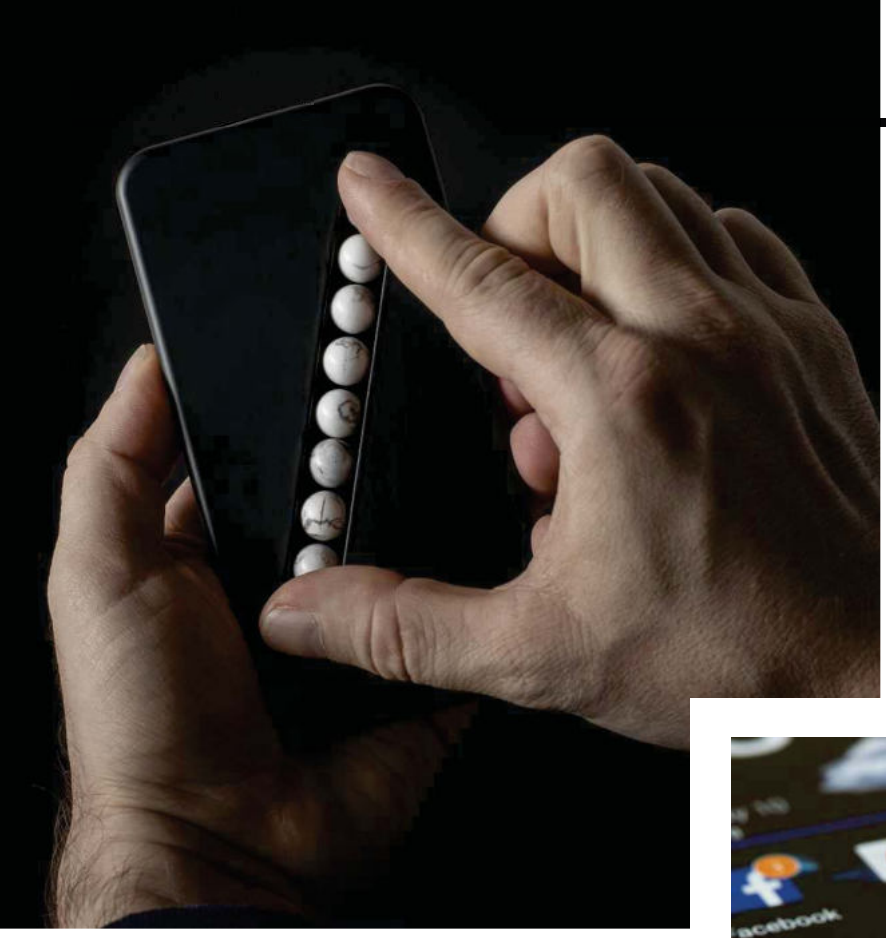
of one particular type of tech can signal a problem. He highlights "the gamers who keep playing the same game, or people going to the same social media channel, or people who'll start a Netflix boxset and won't be able to stop until it's finished – rather than watching one episode and then changing the channel, or doing something different."

Graham also encourages people to be aware of biological changes that may indicate they're on the road to addiction. Most of us need around eight hours of sleep a night, he notes. (We can get by on less, but not without costs to physical or mental health.) If you're not getting enough sleep because of your tech use, or you notice that your body clock is becoming disrupted (perhaps you need an alarm to wake up, or you feel extra lethargic in the morning), these are signs of a problem.

If your eating habits have become irregular, you're skipping meals, or you're opting for ready meals ▶

ABOVE: **When people are hooked on tech, their brains can exhibit similar changes to those seen in individuals who are addicted to drugs**

RIGHT: **The reSTART programme offers a rural retreat for people who are addicted to online gaming, social media and gambling**



ABOVE: **Designer Klemens Schillinger has created substitute phones, complete with tactile beads, that he claims can help smartphone users cope with withdrawal by offering physical stimulation (touching, swiping and scrolling) without connectivity**

OPPOSITE PAGE: **Participant undergoing an MRI scan as part of research into gambling addiction**

so you can quickly get back to a screen, or you're not getting the recommended 30 minutes of exercise a day – these are also indications that tech use may be taking over your life to an unhealthy degree.

You may not be seeing friends as much as you used to, either – but since heavy gamers and social media users will argue that they're interacting with people online, it might be better to focus on the biological signs of a tech problem, Graham suggests. It's also worth noting that there's evidence that online social connections are not equivalent to friendships. One recent study of US adults aged 19 to 32 found that people who reported spending more than two hours a day on platforms such as Facebook, Snapchat and Instagram felt *more* socially isolated than those who spent half an hour or less on these sites per day.

Identifying a problem is an important step, of course. But the question then is, what's to be done?

DIGITAL DETOX

Some researchers are focusing on the devices themselves. A team at Bournemouth University, for example, is advocating for smart warning labels to be built into devices. These labels could establish time limits for device use, and warn users if they're not sticking to them. Unlike the traditional labels found on tobacco and alcohol, the digital labels could be interactive, changing the colour of the screen when the device has been used for a certain amount of time, for example, or sending personalised messages related to the user's interests.

Apps that can help you monitor time online are already available, but people with an addiction – or even a life disruption – need more help. With his tech-addicted patients, Graham usually starts with a 72-hour tech detox, which entails complete tech abstinence. This can be tough, and patients often report the lows associated with withdrawal from an addictive drug. The goal of drug rehab treatment, of course, is total abstinence. But since few of us can live without tech, the next step is to reintroduce it, but in a controlled way.

The detox can have a powerful impact, Graham has found. When he started his tech-addiction service in 2010, he anticipated that patients would need to spend extended periods of time in residential programmes. But he's found that if parents (he specialises in treating adolescents) simply take their tech-addicted child away for a weekend or a longer holiday, without any devices, the results can be profound.

After 72 hours or perhaps a week without tech – and with more sleep, and reduced social anxiety – many patients find they can let go of fears of missing out. "It's like stepping off a merry-go-round," Graham explains. "Things will have moved on in the online world – whether that's news feeds or the latest videos trending or game development. Once they've gotten over that, they feel more rested and more at ease." This allows them to take a more balanced view of the importance of their devices in their lives, Graham says.

After the detox, the gadgets will eventually be switched on again. And then the notifications will start up, demanding instant action and attention. "But in the fight of man versus machine, I think being able to put your smartphone down for a few days and just get a sense of what it's actually like

"During a 72-hour tech detox, patients often report the lows associated with withdrawal from an addictive drug"

PHOTOS: LEONHARD HILZENSAUER, ALAMY, SCIENCE PHOTO LIBRARY, GETTY X3, SHUTTERSTOCK

to feel different again is really helpful," Graham stresses. And this could help those of us who aren't fully addicted to our devices, too, he says.

The next step is to be much tougher about tech use, and to prioritise the things in life that are truly rewarding, rather than giving in to that instant, transient 'hit'. An approach that's been found to work well in treating depression can be helpful here, Graham says. People who are depressed become more socially isolated and do less of the things that make them feel good, whether that's mountain biking or cooking; painting or playing music. If you can schedule in more of these kinds of activities, as well as more face-to-face time with other people and periods of exercise, you will necessarily spend less time with technology. Crucially, these activities will help you feel better about life, too.

This approach can work for those recovering from addiction, as well as the rest of us. "It helps shift the balance," Graham says. "I think for many people, their use of technology can slide into something more like the sort of heavy drinker who no longer even enjoys it, but it's become a habit."

It's unlikely that many of us will be throwing away our smartphones. But being able to recognise when our technology use is becoming excessive, and then scheduling in some time away from our gadgets – whether that's an hour, a day, or an entire weekend – could surely benefit us all.

Emma Young is a science and health journalist and the author of *Sane* (£8.99, Yellow Kite).

DISCOVER MORE

Find out how Daniel Bennett, *BBC Focus's* editor, gets on with a fortnight of dramatically reducing his smartphone use at **sciencefocus.com/techdetox**

UNPLUG YOURSELF

HOW TO LIVE WELL WITH YOUR PHONE

Five tips from Prof Mark Griffiths, psychologist and behavioural addiction expert at Nottingham Trent University

1

1 Step it down gradually
The urge to check your phone can become reflexive and habitual. For some, going a few minutes without checking their phone is difficult. If this sounds like you, try to go 15 minutes without doing it. Once you realise this is possible, increase the length of time you avoid checking to 30 minutes, an hour, and then a few hours a day.

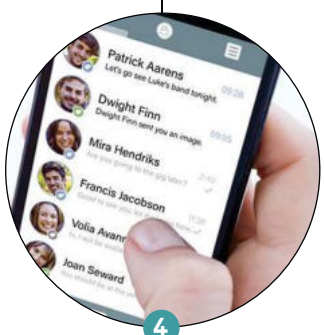
2

2 Monitor usage
Download an app that will tell you how much time you're spending online. (*Moment* and *AntiSocial* are two examples.) This could make you aware of a problem – the first step to a solution.

3

3 Buy an alarm clock
Don't use your phone as an alarm, or you might be tempted to check texts and emails last thing at night and as soon as you wake up. In fact, ban phones from the bedroom. Designate bedtimes and mealtimes as smartphone-free zones. Consider buying a watch, so you're no longer tempted by emails and texts when you check the time.

4 Spring clean your contacts
How many online friends do you actually speak to? Reduce alerts and distractions by removing contacts on social networking sites, deleting unused apps, and unsubscribing from groups that offer little benefit. Consider deleting any games that are taking up a lot of your time.



4

5 Learn to wait
Be mindful of the benefits of not regularly checking your phone. People who react to messages as they arrive tend to write longer responses than those who wait and deal with them all as a block. Waiting will gain you time to spend on other activities.

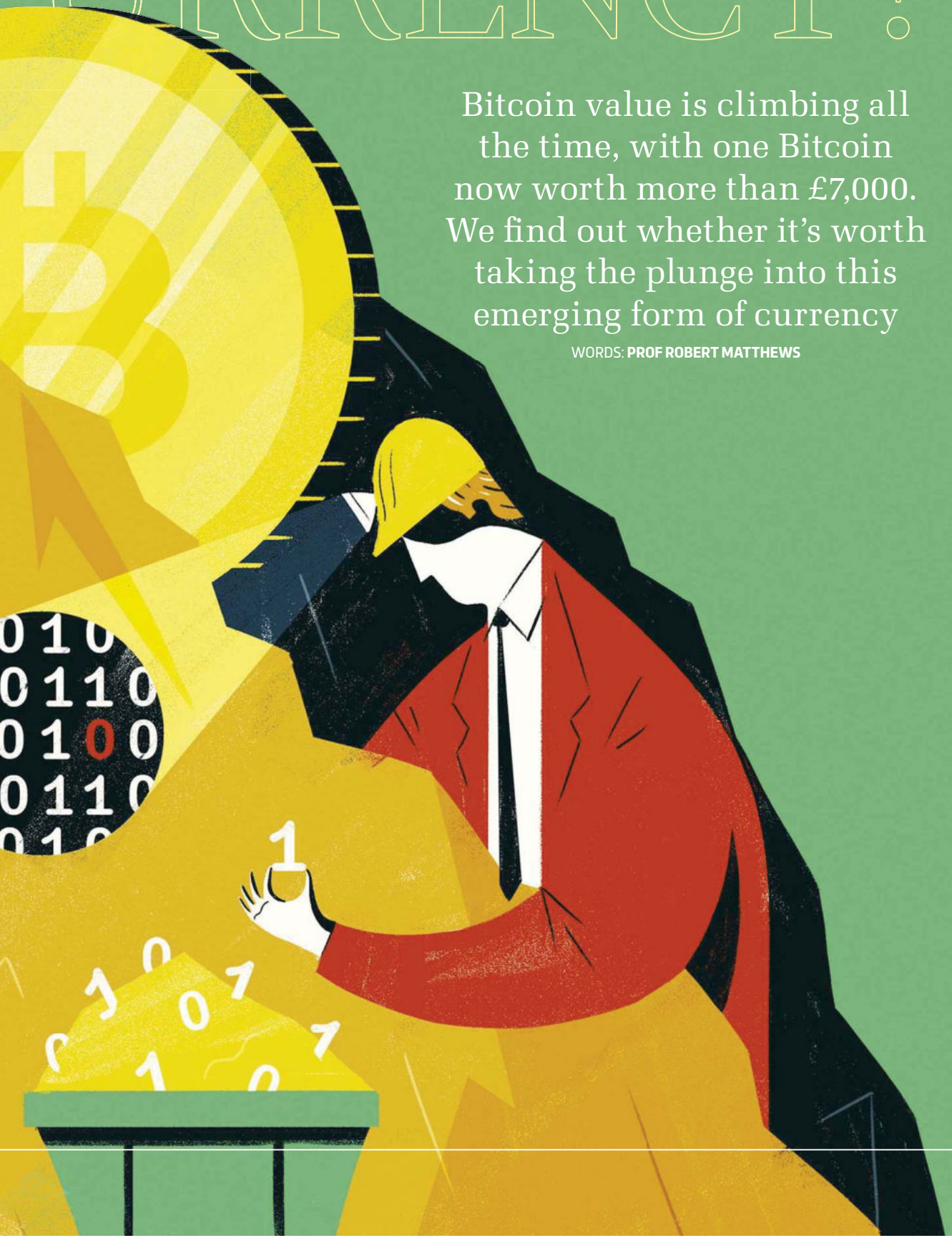
5

SHOULD YOU CRYPTOC

INVEST IN CURRENCY?

Bitcoin value is climbing all the time, with one Bitcoin now worth more than £7,000. We find out whether it's worth taking the plunge into this emerging form of currency

WORDS: **PROF ROBERT MATTHEWS**



They're everywhere from glossy magazines to scuzzy emails, and are accepted by multinationals and assassins. To some, they are the future of money; to others, they are a disaster waiting to happen. Either way, there's no denying the current buzz over cryptocurrencies. From Bitcoin, Litecoin and Ethereum to newcomers like Zcash and Ubiq, there are over 1,000 different varieties to choose from. But should you plunge in or stay well clear? It's a question that's been asked ever since January 2009, when the grandaddy of them emerged from literally nowhere: Bitcoin.

A few months earlier, a message had popped up on a technical mailing list describing a new form of electronic payment. That in itself wasn't particularly exciting: over the years there have been many ideas for new forms of digital cash which for one reason or another have never caught on. But according to its inventor, the elusive Satoshi Nakamoto, Bitcoin was different. It was, he claimed, able to operate completely independently of governments, regulators or banks, yet still be totally trustworthy.

The sheer magnitude of this claim becomes clear as soon as you think how conventional money works. Hard cash – in the form of coins and notes – is physically produced by national mints, and crammed with anti-counterfeiting features to stop people simply making their own whenever they need more. But electronic money, like stocks, shares and any online transactions, isn't real: it's just digital signals, which can just be copied and pasted. To combat this, the global financial system relies on electronic clearing houses that keep tabs on every transaction in an attempt to stop fraud. Or at least, that's what they are supposed to do. In reality, fraudsters and insiders can – and have – found ways to cheat the system. But Nakamoto claimed to have found a way to prevent this. Put simply, Bitcoin works by converting the information about each new transaction into a form that's mathematically almost impossible to read or change, and then entered into a permanent electronic ledger, known as a blockchain.

"To some, cryptocurrencies are the future of money, to others they are a disaster waiting to happen"

TIGHT WAD

As well as being secure, the blockchain doesn't exist in a single place. Instead, it's spread across a virtual network, producing a global system of electronic currency that is fast, efficient and ▶

WHAT IS BLOCKCHAIN?

At the heart of cryptocurrencies like Bitcoin is the electronic ledger, or blockchain, which keeps a permanent and unalterable record of every transaction ever made. It's this that prevents people creating counterfeit Bitcoins. The whereabouts of every genuine transaction is updated on the blockchain, along with a version of the same information that's been mathematically transformed – 'hashed' – in a way that produces a radically different outcome if the information is tampered with. Any attempt to amend a transaction will produce a mismatch that's instantly spotted. For added security, the hashed version of each transaction also depends on parts of the previous transaction, plus some extra ingredients.

Maintaining the blockchain is the job of so-called 'miners', who generate the hashed information using computers and are rewarded for their work with newly minted Bitcoins. It's getting to be a tougher job, as the process of updating the ever-growing blockchain gets more demanding. While once the task could be completed using a home computer, it now requires vast processor farms.

This was all envisaged by Satoshi Nakamoto, the originator of Bitcoins. He wanted to limit their total number to around 21 million, so that they would keep their value over time. That target should be reached by 2140.

What he may not have foreseen were the myriad other uses of the blockchain idea in creating trusted records. Traditional banks are investigating its use for verifying electronic transactions, while hospitals and energy companies are eyeing its use for patient and customer databases.

1 There are more than 1,000 cryptocurrencies, but Bitcoin is the most familiar

2 In 2014, *Newsweek* announced that this man was the creator of Bitcoin, but he claimed to have no involvement with it

3 Enormous servers like this one at a Chinese Bitcoin mine are required if you want to mine for Bitcoins

PHOTOS: GETTY X3 ILLUSTRATION: CATHAL DUANE

PHOTO: GETTY ILLUSTRATION: CATHAL DUANE

trustworthy – and out of the hands of governments or banks. Cutting out the financial establishment seems to have been a big motivator for Nakamoto. When Bitcoin was launched, the world was in the grip of the worst financial crisis since the 1930s. Banks were widely seen as the culprits, yet governments were racing to bail them out. This infuriated many, who believed the banks should suffer the consequences.

"One reason Bitcoin has captured the imagination of so many people is that it holds the promise of democratising finance," says David Orrell, co-author of the *The Evolution Of Money*.

One key appeal of cryptocurrencies is the ability to perform transactions completely outside the standard banking system. Two 'mainstream' benefits of this are an ability to carry out transactions and dodge the fees levied by banks, like when you want to send money abroad, and also to avoid sales taxes like VAT.

Intriguingly, when Nakamoto 'mined' the first Bitcoins, they came embedded with the text of a headline describing how the UK government was about to give banks a second bailout. Was this an early hint of Nakamoto's motivations in launching an independent currency? It's impossible to know, as no one knows who or where Nakamoto is; he (or she) vanished in 2010. Attempts to extract clues from his postings have come to naught. In 2014, *Newsweek* seemed to have found him in California, but the person insisted he knew nothing about Bitcoin. Some suspect 'Nakamoto' is a pseudonym for a team of cryptocurrency experts.

Whatever Nakomoto's motivation, there's no doubt it was shared by others. At first, Bitcoins were limited to a small community of enthusiasts. With relatively few in existence and little interest, the economic law of supply and demand meant that Bitcoins were virtually worthless. When one developer performed the first-ever cryptocurrency transaction in May 2010 – the purchase of two pizzas – they cost him 10,000 Bitcoins.

But within months, the mainstream media started covering the idea. Demand soared, and by February 2011 a Bitcoin was worth the same as $1, and in June 2011 the price hit almost $30 – making those two pizzas the costliest in history. But days later, disaster struck. A Tokyo-based Bitcoin exchange called Mt Gox announced it had 'lost' hundreds of thousands of Bitcoins. Exactly where they went is still disputed. What isn't in doubt is that the incident dealt a severe blow to trust in Bitcoin. Early adopters of the cryptocurrency quit, and the value of Bitcoins plunged. By the end of 2011, the whole idea seemed dead.

LEGAL TENDER?

Yet Bitcoin's ability to make and receive payments without using banks remained attractive to one sector of the economy: criminals. They were drawn to Bitcoin thanks to its ability to perform transactions completely outside the standard banking system. Of course, this means no one knows who's getting what, which is great if you're up to no good.

Bitcoins became the currency of choice for drug dealers, money launderers and users of the 'dark web'. While these propped up Bitcoin, other cryptocurrencies started to emerge, lacking the image problem of the original.

"Bitcoins became the currency of choice for drug dealers and money launderers"

HOW TO GET INVOLVED

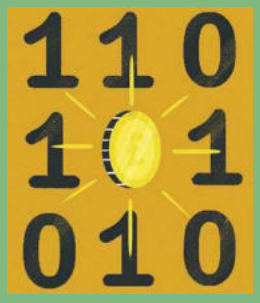
There are two basic ways of getting involved in cryptocurrency: as a means of paying for stuff, and as an investment. But however you do it, you need to proceed with care. Cryptocurrencies exist only electronically, making them targets for a global network of sophisticated digital scammers, thieves and hackers. And as the whole idea of cryptocurrency is to offer an alternative to official money, if something goes wrong you won't be able to run to your bank for help. If you're still undeterred, then here's what to do...

GET A DIGITAL WALLET

This is where you keep your currency, allowing you to send or receive payments from your computer or smartphone. Digital wallets include security features designed to keep your currency safe. One of the most popular and well-regarded wallets is operated by **Blockchain.info** in Luxembourg.

ACTIVATE THE SECURITY MEASURES

Once you've registered your wallet, you'll need to secure your account to prevent the contents of your wallet being hijacked or blocked by hackers. To do this, you'll need a unique Wallet ID and extremely strong access passwords that have to be stored offline. The two-step verification involves your mobile phone, among other features.



CONVERT YOUR CASH INTO CRYPTOCURRENCY

This involves finding a so-called broker. This is essentially a bureau de change, where instead of buying holiday money you're buying cryptocurrency. There are many to choose from, and sites like BittyBot provide price comparisons. Making the right choice depends on many factors and can be intimidating.

BUY STUFF, OR HOARD AND HOPE

A growing number of retailers now accept cryptocurrency as payment, though the black market still offers the most opportunities. But increasingly people are viewing cryptocurrency like gold: something to be bought and kept in the hope its value goes up. The huge swings in value can, however, make investing in cryptocurrency a terrifying experience.

In 2015 a team of leading developers led by Vitalik Buterin, a brilliant 21-year-old Russian-Canadian programmer, launched Ethereum, which combines a cryptocurrency known as Ether with other features like virtual contracts. These allow the cryptocurrency to be used in crowdsourcing campaigns, eliminating the need to use platforms like Kickstarter.

Yet like Bitcoin, Ethereum has faced challenges. It has been attacked by hackers, and its value has lurched violently since its launch. Even so, it has created a sense that cryptocurrencies are here to stay.

"Central governments are obviously concerned about losing control," says Lars Kroijer, former hedge fund manager and author of *Investing Demystified*. "But the kind of technology cryptocurrencies represents is hard to put back in the box."

Bitcoin and Ether are now just the best known of hundreds of cryptocurrencies currently in existence. At the time of writing, there are around 17 million Bitcoins, each worth more than $10,000. The main driver for this growth is simple speculation, with people piling in just because they think they can make a profit before everyone wakes up and realises it makes no sense. There's some evidence of other, more technical drivers, but these seem less important. With conventional currencies, reliability is linked to political stability and strong economies, like those of Norway and Switzerland. These rules simply don't apply to cryptocurrencies, as there's no political structure or underlying economic strength. So, the exchange rate is determined entirely by sentiment, which can change in an instant, leading to huge volatility.

So, will cryptocurrency be the Next Big Thing in the long history of money? With the Japanese government now accepting Bitcoin as legal tender, and household names like Microsoft and Expedia allowing them as payment, there are signs they're shaking off their shady past. But many experts remain unconvinced. "Cryptocurrencies can and do fulfil the function of money, but few consumers will want to use currencies whose value swings around quite so wildly," says Russ Mould, investment director at stockbrokers AJ Bell. He believes their use as an alternative to 'official' money is being overshadowed by attempts to simply hoard them in the hope they'll gain value. "This is rarely a good sign," warns Mould, who points to historical parallels with speculative 'bubbles' that burst, leaving investors destitute.

Yet while the future of cryptocurrencies remains in doubt, their underlying blockchain technology is already finding uses beyond finance. Ironically, its ability to digitise trust may prove the mysterious Mr Nakamoto's greatest legacy.

Prof Robert Matthews is a visiting professor in science at Aston University, Birmingham. His latest book is *Chancing It: The Laws Of Chance And How They Can Work for You* (£14.99, Profile).

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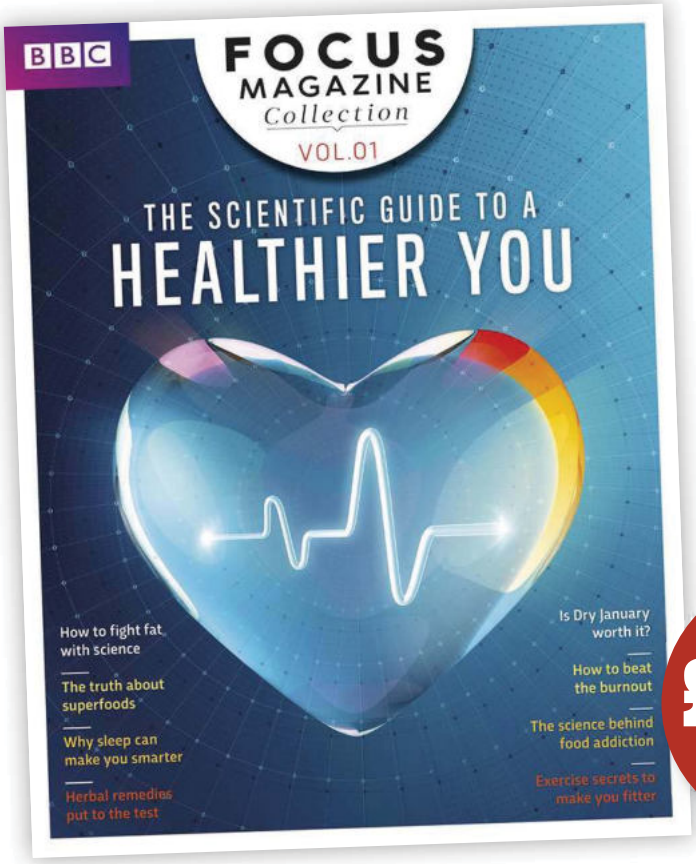

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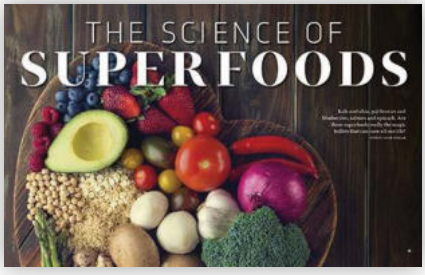

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HELEN CZERSKI ON... CHAMPAGNE CORKS

"THE POP AND FIZZ OF CHAMPAGNE ARE EXCITING, BUT THE CORK ITSELF HAS A STORY TO TELL TOO"

There was never a conscious decision to start a collection. But I'm a bubble physicist, so I notice champagne (usually as a toy first and a drink second), and some years ago I started picking up the corks. I put a couple of them in a bowl in my living room, with the matches and tealights and other such miscellany, and every so often another one would come along. Eventually, the corks outnumbered everything else, and the rest got booted out. I looked at them properly for the first time this week, and wished it hadn't taken me so long to appreciate them. Form and function are so beautifully intertwined, and it all starts with an obvious question: why do they have that peculiar mushroom shape?

Champagne corks are distinctive, and it's all down to the bubbles in the drink. The pressure inside a bottle of champagne is around six times atmospheric pressure, and the small region of gas at the top of the bottle is entirely filled with carbon dioxide at that pressure. But there's even more carbon dioxide dissolved in the champagne itself – you would need a five-litre balloon to hold it all – and the high pressure is essential to keep it there. You can't afford to let gas leak through the cork, because if the pressure drops, you'll have flat champagne. And the cork also has to stay put even though there's all that pressure pushing outwards on it.

The solution is a brilliant natural material from the outer layer of the cork oak. It's got a honeycomb-like structure made of tiny empty cells with zigzag walls. If you squish it, the walls will compress like a concertina and then recover their shape when you let go. Champagne manufacturers take a cylinder with a diameter about 1cm greater than the neck of the bottle, squash it inwards until it's slender enough to fit, and then let go. The section sticking out from the top of the bottle springs back to its original diameter, and the bit inside the neck springs back as much as it can, pushing strongly outwards and sealing the bottle. This does a pretty good job of sealing the gas in, although a little does escape – an older champagne has about 25 per cent less gas in it than one 15 years younger. You can recover the cork's original shape if you put it in boiling water.

But a champagne cork that's been removed from the bottle has a waist – it's wider at the base than in the middle. Why?

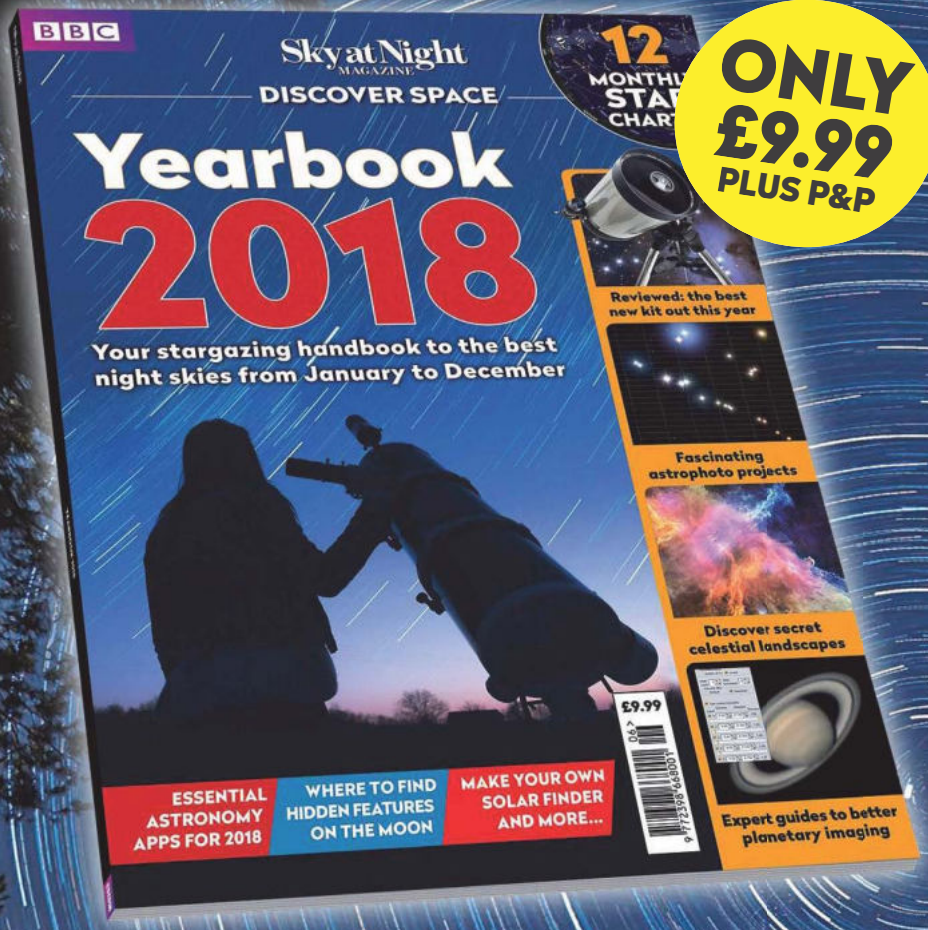
When I looked at my corks, I noticed that they all have the same structure. They're made from lots of tiny bits of cork all compressed together to form a conglomerate, but they have two whole disks of cork at the bottom, each about 6mm thick. These are the highest quality natural cork, and you can see dark channels running along the sides of the disks, showing themselves as dots at the bottom. These are lenticels, and they run from the inside of the tree to the outside to let it breathe. When you cut the disks this way, they are extremely springy sideways – fabulous for sealing the wine in. But the channels are a problem. So the manufacturers stack two disks on top of each other. This means they keep the springiness, but the channels don't line up so gas can't escape. And this is the reason for the mushroom shape. When the cork escapes from the bottle, the disks return to pretty much exactly their original diameter. But the conglomerate cork above isn't as elastic, and stays compressed.

So if you hear a 'pop!' anywhere near you this winter, go and find the cork. The pop and the fizz are exciting, but the cork itself has a story to tell too. Happy 2018!

Dr Helen Czerski is a physicist and BBC presenter. Her latest book is *Storm In A Teacup* (£18.99, Transworld).

NEXT ISSUE: FROSTY FROLICS

ILLUSTRATION: KYLE SMART



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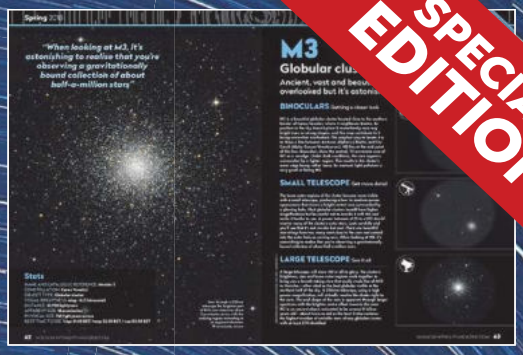

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Q&A

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LUIS VILLAZON
Science/tech writer

DR AARATHI PRASAD
Biologist, geneticist

PROF ROBERT MATTHEWS
Physicist, science writer

YOUR QUESTIONS ANSWERED

JANUARY 2018

EDITED BY EMMA BAYLEY

PHOTO: GETTY

Is muscle memory real?

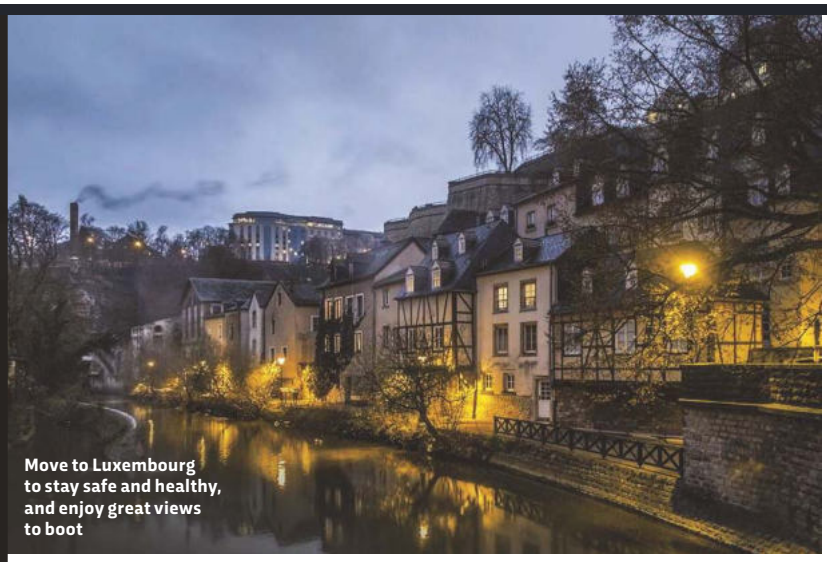
SIMON TAYLOR, LONDON

There are two kinds, both very real. The first, properly called 'procedural memory' strengthens the synaptic pathways in your brain for specific coordinated sequences of muscle movements that you perform often. This is what allows a guitar player to form the chord shapes without consciously considering the position of each finger, for example. There is another kind of muscle memory though. If you have previously put on muscle mass through training, then it is easier to bulk up again in the future than if you had never trained before. Muscle cells gain extra nuclei during training and these can last for 15 years, even after the muscle fibres have shrunk back to normal size. It is as if the muscles 'remember' their previous strength and find it easier to return to that level. LV

How does ocean acidification impact marine life?

KAREN DRAKE, CHELMSFORD

There'll be many losers, and perhaps some winners among marine life as the oceans absorb humanity's CO_2 and pH falls. An eight-year study involving 250 scientists recently revealed a complex picture of changes rippling through food webs. Organisms with carbonate exoskeletons – like starfish, mussels and swimming snails called sea butterflies – tend to suffer because their shells become unstable. Young animals are especially at risk; cod larvae are twice as likely to die at lower pH. Barnacles and a few other robust animals can adapt but may still suffer from the combined impacts of other threats, like plastic pollution and rising temperatures. HS



Move to Luxembourg to stay safe and healthy, and enjoy great views to boot

Where's the safest place on Earth to live?

ANTONY INGRAM, WELLINGBOROUGH

The solitary confinement cells at the ADX Florence 'supermax' prison in Florida will keep you safe from most direct physical threats, including other prisoners. But your mental health will certainly suffer. If you want to live a more normal life while keeping safe, try Singapore, which was ranked the safest country in 2016 by the Legatum Institute. To keep safe from disease, move to Luxembourg, which scored top for health and was still in second place for security. **LV**

Will Europe get more hurricanes in the future?

PETER JENKINS, MANCHESTER

Hurricanes form over warm ocean waters, making them relatively uncommon in Europe. Hurricanes born in tropical Atlantic waters are occasionally diverted northwest by the jet stream, but gradually peter out as they hit colder waters. By the time they arrive in Europe they may no longer technically be classified as a hurricane, but can still cause heavy rain and high winds, as seen with ex-hurricane Ophelia in October. As our climate changes, warmer waters in the North Atlantic could lead to hurricanes retaining their intensity over greater distances, increasing the frequency with which such 'super storms' occur in western Europe. **AFC**

How much of a cereal box gets reused when it is recycled?

EDDIE CULLEN, LOTHERSDALE

Cereal boxes are made from paperboard, and, save for inks and glue, the entirety of a recycled box can be reused. Many cereal boxes are already made from recycled paper. At a recycling plant, paperboard is mixed with water and broken down into pulp, then washed and filtered to remove inks, coatings and other contaminants. Each time paper is recycled, the mechanical action involved weakens its fibres – after six cycles they are usually too worn out to reuse. A recycled cereal box might be used for cardboard packaging again, or could begin a new life as soundproofing material, insulation or pet bedding. AFC

PHOTOS: GETTY X5, ALAMY ILLUSTRATIONS: RAJA LOCKEY

IN NUMBERS

351

The number of bacteria species harboured by house flies. Urgh!

3,000

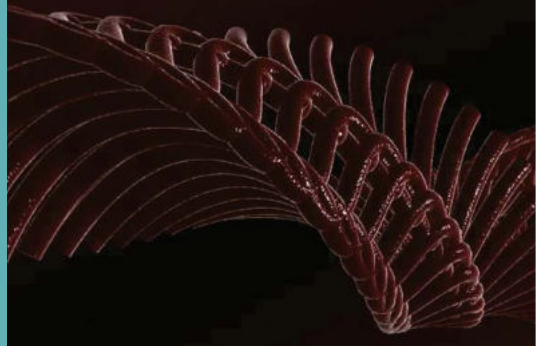
The number of breeding pairs of red kites in the UK. Just 30 years ago, they were on the brink of extinction.

49

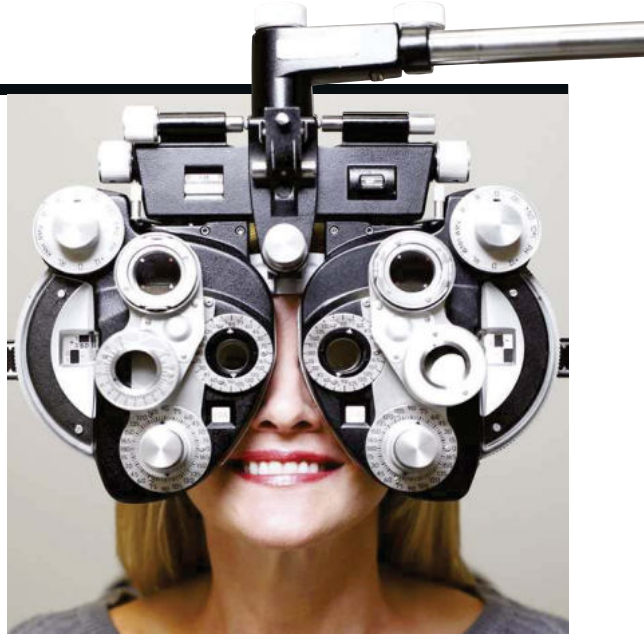
The minimum number of genes that contribute to whether your earlobes are 'attached' or 'free'.

Would alien life need to have DNA?

WENDY BEECH, LEWES



The role of DNA is to provide instructions that allow amino acids (the building blocks of proteins needed for the processes of life) to be assembled correctly. DNA also allows those same instructions to be passed down the generations. But DNA isn't unique in this ability, as the related molecule RNA can perform similar functions. It's also possible that alien life exploits radically different ways of achieving similar ends. RM



Is human eyesight getting worse?

TONY HERSH, NEWBURY

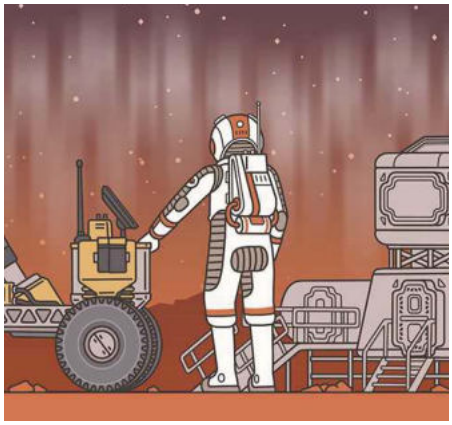
Shortsightedness (myopia) certainly is. There has been an epidemic of myopia in the last 100 years and a third of adults in the US and 90 per cent of adults in Taiwan now need to wear corrective lenses. Myopia is inherited, but the reason for the recent increase seems to be more time spent indoors looking at close objects, especially books and screens. **LV**

THE THOUGHT EXPERIMENT

WHAT WOULD LIVING ON MARS DO TO MY BODY?

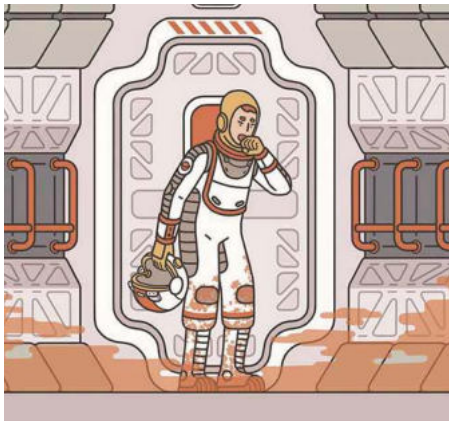
1. LOWER GRAVITY

The effects of zero gravity have been studied on the International Space Station, but the long term impact of low gravity is unknown. An hour in a special gym each day might be enough to stave off muscle wasting and bone loss. But reduced gravity also lowers red blood cell counts and compromises your immune system, and a treadmill won't help with that.



2. RADIATION

The surface radiation on Mars is 0.67mSv per day, which is the equivalent exposure of a daily hip X-ray. This radiation is mostly in the form of galactic cosmic rays. Martian soil could be used to shield a Mars base from the rays, but the covering would need to be five metres thick. Even for a three-year round trip to Mars, studies predict a 10 per cent chance of developing a fatal cancer.



3. TOXIC SOIL

Martian topsoil is full of highly reactive perchlorates, formed by the action of UV rays. Some of this dust will inevitably be tracked into the Mars base and be inhaled or ingested. Perchlorate poisoning is reversible, but on Mars you'll be constantly exposed. Just 25 parts per billion in drinking water will suppress thyroid function and raise blood pressure. Higher doses cause lung damage.

It is thought that the Sphinx was built during the reign of Khafre (2558-2532 BC)

Why do we have to dig so deep to uncover ancient ruins?

NIKKOLA FURFARO, AUSTRALIA

There is a survivorship bias at work here: buildings and monuments left exposed on the surface don't last very long. Humans steal the best bits to reuse in other buildings, and erosion wears everything else to dust. So the only ancient ruins we find are the ones that were buried. But they got buried in the first place because the ground level of ancient cities tended to steadily rise. Settlements constantly imported food and building materials for the population, but getting rid of waste and rubbish was a much lower priority. New houses were built on top of the ruins of old ones because hauling away rubble was labour intensive and it was much easier to simply spread it out and build straight on top. Rivers periodically flooded and added a layer of silt, while in dry regions the wind was constantly blowing in sand and dust. (The Sphinx was buried up to its head in sand until archaeologists re-excavated it in 1817.) When ancient towns were abandoned entirely, plant seeds quickly took root and created more bulk from the CO_2 they pulled from the air. Their roots stabilised the soil created from rotting plant matter and the layers gradually built up. **LV**

QUESTION OF THE MONTH

How dense is the Universe?

LEWIS RYLANDS, LIVERPOOL

WINNER!

Lewis Rylands wins a Nuki Smart Lock, (£200 approx, **nuki.io**). Nuki transforms your front door into a smart lock, allowing you to monitor who visits. It will also know when you're at the door and will open it for you, saving you rummaging in your bag for your keys when it's wet outside. It even automatically locks the door when you leave!

By making observations of fluctuations in the cosmic microwave background (the 'leftover' radiation from the Big Bang), astronomers have shown that the Universe is 'flat'. This means that its density appears to be close to the critical density, which is the density needed for gravity to just halt its expansion after an infinite time. The expansion rate we see today indicates that the critical density of the Universe is about 9×10^{-27} kg m^{-3}. This density, however, is the total density of both matter and energy. Observations have shown that ordinary matter accounts for 4.9 per cent of this density, while 26.8 per cent of it is due to dark matter, a form of matter not directly visible. The remaining 68.3 per cent is due to dark energy, a mysterious energy field causing the Universe's expansion to accelerate. So, ordinary matter has a density corresponding to about one proton for every four cubic metres of volume. The nature of dark matter and dark energy are not fully understood. AGu

PHOTOS: GETTY X4, CATERS NEWS

How strong is an ant?

CHARLIE REES, BROMLEY

Asian weaver ants can carry 500mg – about 100 times their body weight. At their tiny scale though, carrying heavy objects is less about muscle strength and more about grip. Ants have self-cleaning sticky pads on their feet and can vary the size of the contact patch on the ground so they aren't overbalanced by their load, even when upside-down! **LV**

Love our Q&A pages? Follow our Twitter feed @sciencefocusQA

Why is gold yellow?

DAVID MIEDUNIECKI, FRANCE

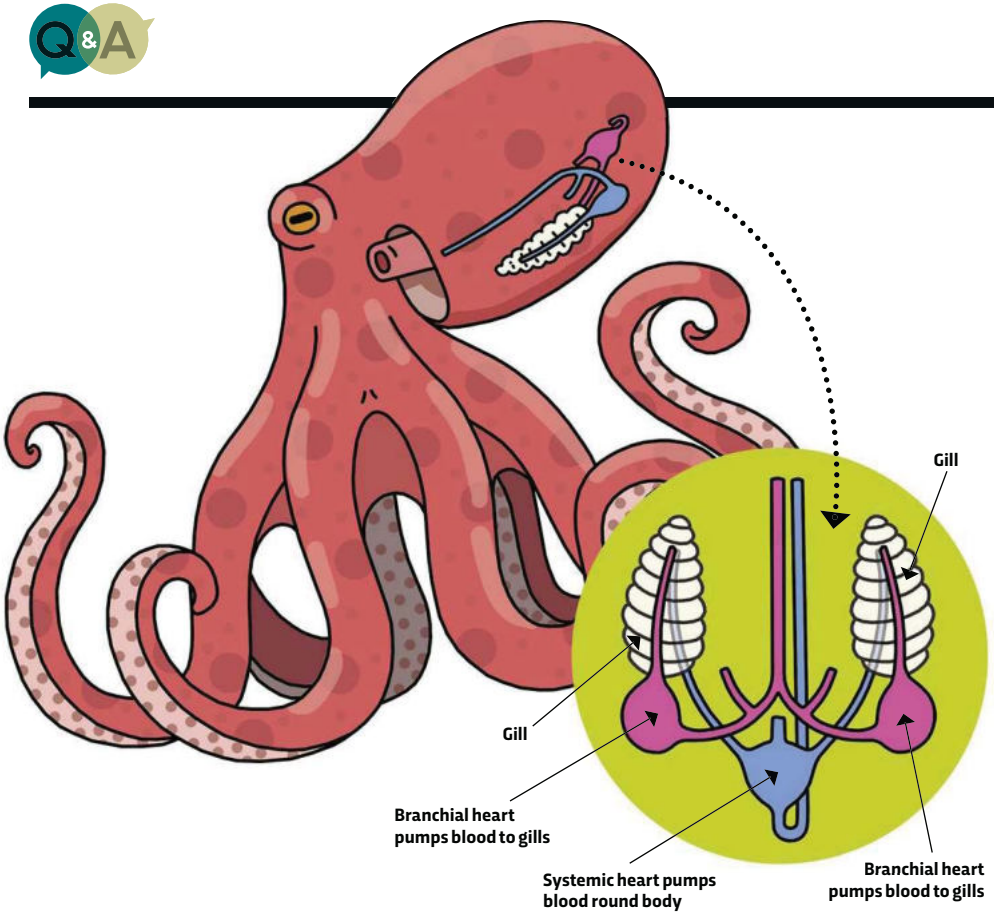
Simple chemistry predicts that gold and silver should have the same silvery appearance. To explain gold's colour we need something else – a mix of quantum mechanics and Einstein's Special Relativity.

Quantum mechanics describes an atom's electrons sitting in discrete orbitals. In the case of silver, it takes a high-energy, ultraviolet photon to kick an electron up to a higher orbital. Lower-energy, visible photons are reflected back so silver acts like a mirror. Relativity comes into play because, due to the size of gold atoms, its electrons are travelling at over half the speed of light. Einstein's theory tells us that at these speeds the mass of the electrons increases, which in turn means the energy needed to kick them up to another orbital is reduced. So lower-energy blue photons are absorbed, and don't get reflected by the gold. And if blue is removed, we see yellow. **ML**

Am I more likely to get a cold if I'm short of sleep?

ALICE PARKER, CARDIFF

There is some evidence to support this idea. In a study conducted by researchers from the US, the sleep of 164 participants was assessed over a week. Those in the study were then given some nasal drops containing rhinovirus, and monitored for five days to see if they developed signs of a cold. As assessed by actigraphs (watch-like devices), those who slept for short periods (up to six hours a night) were more likely to develop a cold than those who slept for longer periods (over seven hours a night). This finding chimes well with other research showing that if we miss out on sleep for even a single night, our immune system is compromised. **AGr**



Why does an octopus have more than one heart?

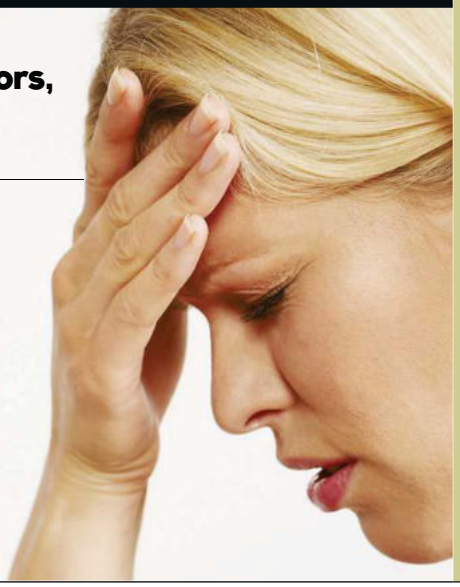
LOUISE DENVER, SOUTHAMPTON

Octopuses have three hearts: one pumps blood around the body; the other two pump blood to the gills. The reason for this impressive cardiac hardware probably comes down to the unusual composition of their blood. Unlike vertebrates that have iron-rich haemoglobin packed into red blood cells, octopuses – along with some tarantulas, scorpions and horseshoe crabs – have copper-rich haemocyanin dissolved directly in their blood (this means their blood is blue!). Haemocyanin is less efficient than haemoglobin as an oxygen transporter. The three hearts help to compensate for this by pumping blood at higher pressure around the body to supply the octopuses' active lifestyle. **HS**

If the brain has no pain receptors, why do I get headaches?

JOEL TAYLOR, WILLAND

That's why they are called headaches, not brainaches! Although the brain doesn't sense pain directly, it is surrounded by membranes, blood vessels and muscles that do. Ordinary tension headaches are caused by the muscles in your scalp and neck. The origin of the pain in a migraine headache isn't fully understood yet, but it may come from the arteries that supply the brain. The brain is just bad at locating the origin of these signals. **LV**



WHAT CONNECTS...

...THE NUMBER 4 AND THE DAY YOU WILL DIE?

1. Numerology
The number 4 is unlucky in China and Japan. This is because the word for the number 4 ('sei') is pronounced the same as the word for death or suffering.

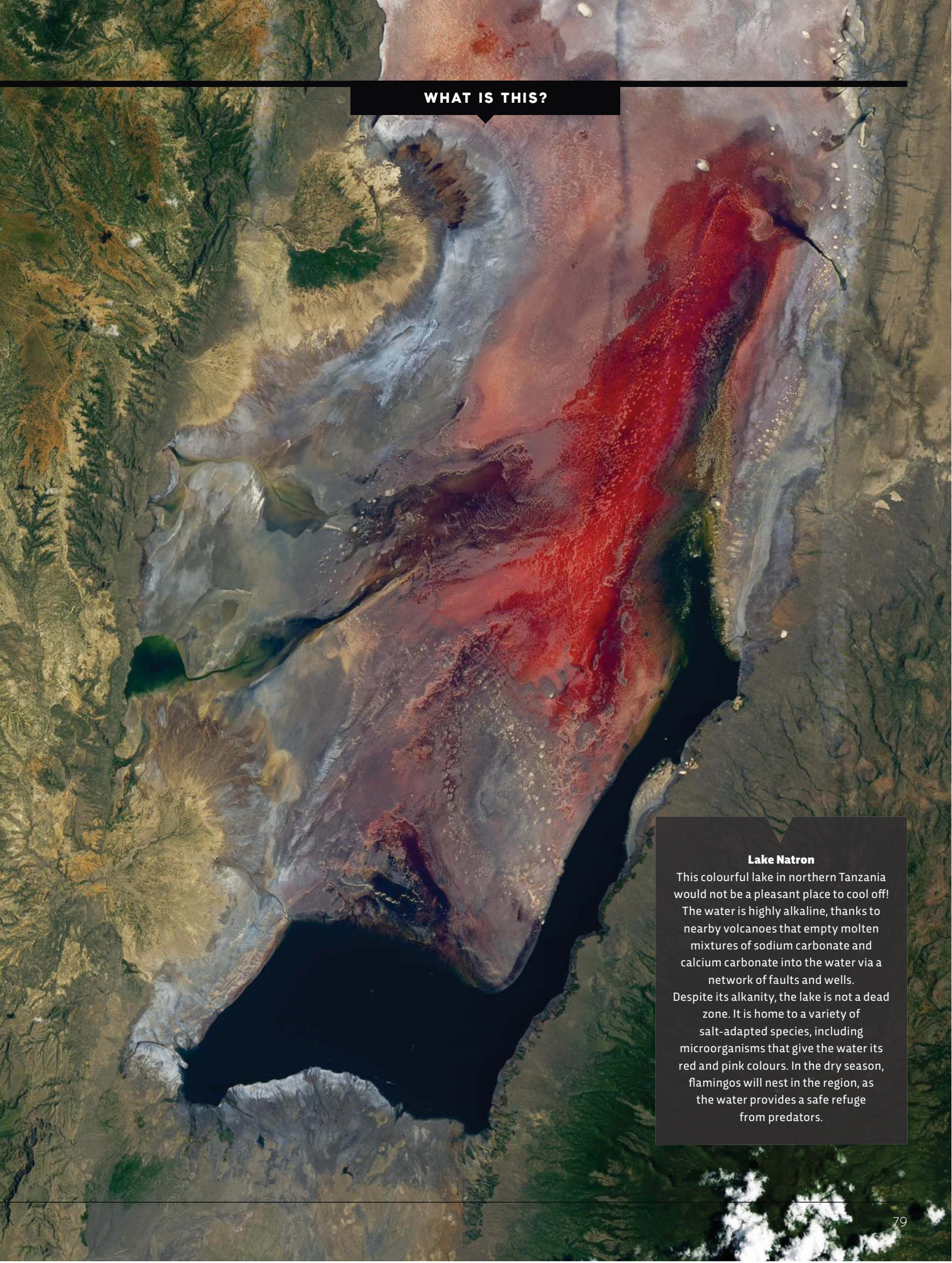
2. Stress
The *Hound Of The Baskervilles Effect*, named after the Sherlock Holmes story, is a real phenomenon that increases your chance of a heart attack when you are suffering from psychological stress.

3. Death
A 2001 study at UC San Diego investigated the *Hound Of The Baskervilles Effect*, and found that people of Japanese and Chinese origin are more likely to have a fatal heart attack on the 4th of any month.

4. Superstition
Yet studies have failed to find any increase in heart attacks on Friday 13th. This may be because it's merely considered unlucky, rather than being associated with death.

PHOTOS: GETTY X3, ALAMY, NASA VISIBLE EARTH ILLUSTRATION: RAJA LOCKEY

WHAT IS THIS?



Lake Natron

This colourful lake in northern Tanzania would not be a pleasant place to cool off! The water is highly alkaline, thanks to nearby volcanoes that empty molten mixtures of sodium carbonate and calcium carbonate into the water via a network of faults and wells.

Despite its alkanity, the lake is not a dead zone. It is home to a variety of salt-adapted species, including microorganisms that give the water its red and pink colours. In the dry season, flamingos will nest in the region, as the water provides a safe refuge from predators.

TOP 10

MOST VITAMIN D RICH FOODS

(Figures in International Units, recommended daily amount is 400IU)

1. Cod liver oil
Per portion: 440
Per 100g: 9,780

2. Salmon and mackerel
Per portion: 400
Per 100g: 470

3. Tinned sardines
Per portion: 270
Per 100g: 270

4. Tinned tuna
Per portion: 154
Per 100g: 181

5. Almond milk
Per portion: 68
Per 100g: 30

6. Breakfast cereal
Per portion: 52
Per 100g: 168

7. Eggs
Per portion: 41
Per 100g: 73

8. Shiitake mushrooms
Per portion: 40
Per 100g: 53

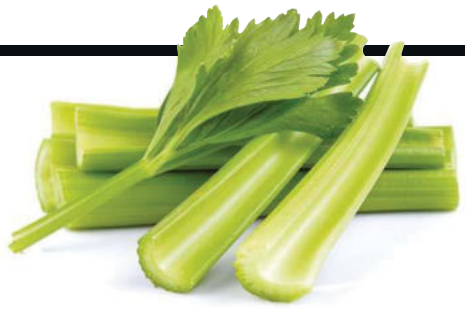
9. Caviar
Per portion: 33
Per 100g: 116

10. Margarine
Per portion: 30
Per 100g: 300

Why do passenger aircraft fly so high?

KATIE BARKER, LEAMINGTON SPA

There are lots of benefits to flying at an altitude of 11km. The air is thinner, producing less aerodynamic drag and thus reducing fuel consumption. It is also cold, around -55°C, which boosts the efficiency of the jet engines. Plus, this part of the atmosphere – known as the stratosphere – is less turbulent, making for a smoother flight. **RM**



Is celery really a negative calorie food?

PHIL O'FARRELL, HEBDEN BRIDGE

A stick of celery contains about six calories; chewing and digesting it will only take half a calorie. However, the rest of your metabolism doesn't stop just because you are eating celery and a 2016 study found that a stick of celery provides 19 fewer calories than you normally burn during the time you are eating it. So you'll still starve on a diet of celery, just more slowly than not eating at all. **LV**

Geological faults can clearly be seen on this rocky outcrop in Devon

Does continental drift affect the climate?

TAMARA SIMMONS, LINCOLN

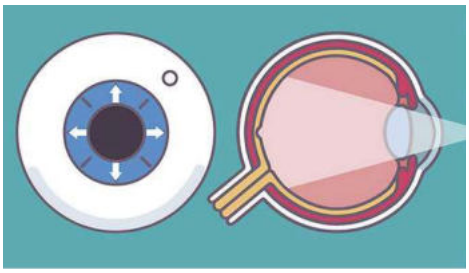
Propelled by the circulating heat of the Earth's interior, the vast rocky plates forming the crust move barely a few centimetres a year. Yet over time they have had a profound influence on the Earth's climate. Today's continents were once part of a huge supercontinent known as Pangaea, which began to break apart around 175 million years ago. At the time, the planet was much warmer than today, but the fragmentation of Pangaea led to massive changes in land distribution and ocean and atmospheric circulation patterns, triggering radical climate change. Collisions between plates have triggered further change. For example, around 35 million years ago the plate carrying modern-day India started pushing under the Asia plate to create the Himalayas, which affect global wind patterns and drive the monsoon season to this day. **RM**

PHOTOS: GETTY X4 ILLUSTRATIONS: RAJA LOCKEY

WHAT HAPPENS IN MY BODY...

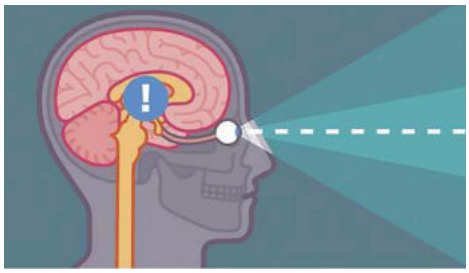
...WHEN I HAVE A PANIC ATTACK?

Humans have evolved behaviours to deal with sudden physical threats, such as predators. These are triggered automatically without conscious thought, to quickly prepare the body for running away or standing and fighting. But modern life is mostly free of marauding bears and this threat response can be accidentally triggered by emotional stress instead. A panic attack is like the smoke alarm going off when you burn the toast, even though the house isn't on fire.



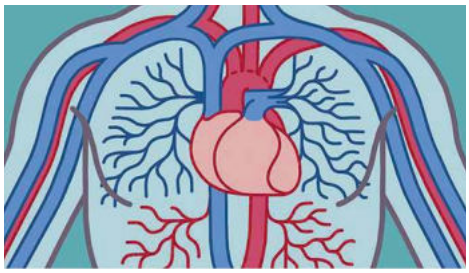
1. Eyes

Pupils open wider to increase the light reaching the retina. This boosts vision in low light and improves the 'frame rate' for rapidly moving objects.



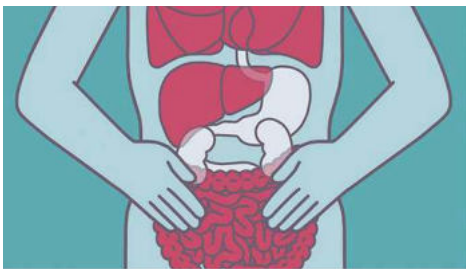
2. Brain

Attention narrows to focus exclusively on the perceived source of the threat. If there is no physical danger, this can feel like tunnel vision.



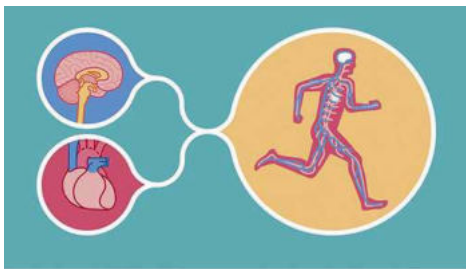
3. Heart

Pulse rate rises. Your chest feels like it is thumping and you hear the sudden swooshing in your ears as your blood flow increases.



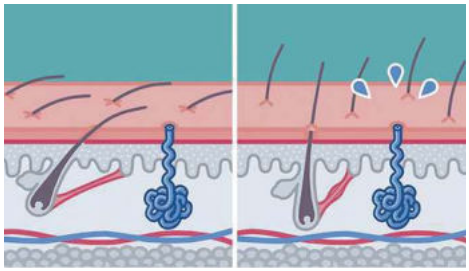
4. Stomach

Blood is diverted away from your stomach and kidneys, because these are less important in a crisis. This can make you feel sick.



5. Legs

Your circulation and nervous system are getting your legs ready to run. If you have nothing to flee, the muscles will begin trembling uncontrollably.



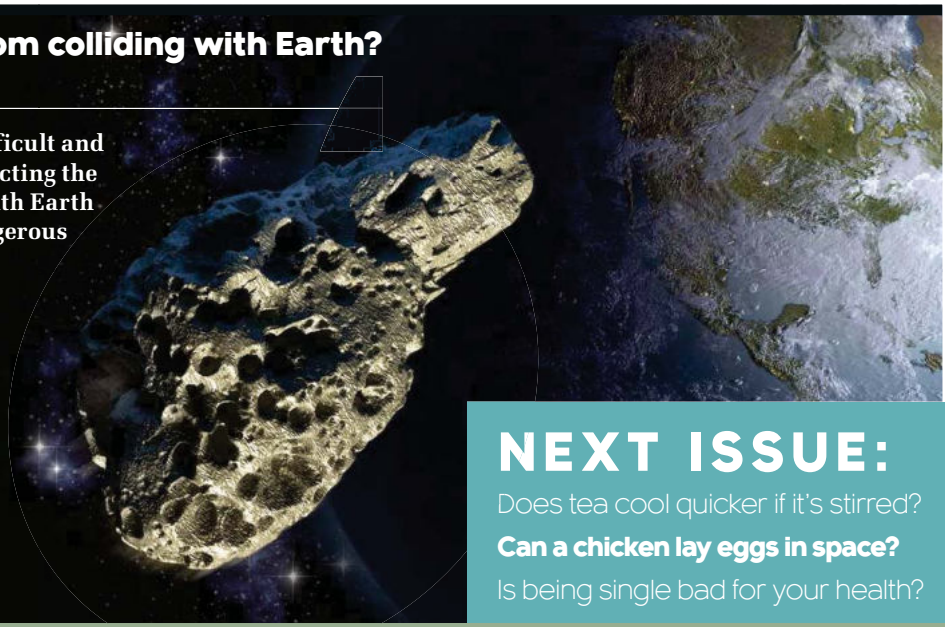
6. Skin

You sweat because your body is preparing to shed the excess heat from sudden exercise. Hair stands on end to make you seem larger to predators.

Could we stop an asteroid from colliding with Earth?

JAMIE REMINGTON, ANDOVER

It is certainly possible, but would be a difficult and expensive task. The key would be in deflecting the asteroid away from its collision course with Earth rather than shattering it into equally dangerous debris. This could be done by impacting it with a non-destructive projectile, simply tugging the asteroid into a different orbit with a nearby high-mass spacecraft, ablating the asteroid's surface with a high-power laser (or a nearby nuclear explosion), or by placing small rockets on the asteroid's surface. All of these techniques would require at least five years to achieve, which is why early warning of potential asteroid impacts is vitally important. AGu



NEXT ISSUE:

Does tea cool quicker if it's stirred?

Can a chicken lay eggs in space?

Is being single bad for your health?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

JANUARY 2018 | EDITED BY JAMES LLOYD

PHOTO: BBC

01

ANIMALS WITH CAMERAS
BBC ONE, FROM 1 FEBRUARY.

TAKE AN ANIMAL'S-EYE VIEW

Deep underground, at the bottom of the ocean, high up in the jungle… animals spend a lot of time in places that are difficult for us to visit. But what if the animals could take us there themselves? What if we gave them cameras to film from their own perspective?

That's the premise of new three-part series *Animals With Cameras*, which uses the latest camera technology to take us deep into the world of animals, capturing previously unseen behaviour. We'll observe chimpanzees washing their hands and building treetop nests in Cameroon, ride with cheetahs as they hunt for prey in the tangled woodlands of Namibia, and find out who looks after baby meerkats in their underground burrows when their mum is out foraging.

Throughout the series, presenter and wildlife cameraman Gordon Buchanan will work closely with the scientists for whom this unique footage will answer vital questions about the animals' lives. Turn over to find out more about how the series was made. ▶

FIND OUT MORE

For more of this month's best events, shows and books, head to **bit.ly/BBCFocusBrainFood**

Q&A: GORDON BUCHANAN

Presenter of *Animals With Cameras*

What benefits do you get from filming from the animals' perspective?
We have all this information about animals' lives, but the one thing we're usually missing is actually seeing what the animal sees. Chimpanzees spend a lot of their lives hidden in thick foliage up tall trees, brown bears in the mountains of Turkey are so secretive that the majority of people in that part of the world haven't even seen one, and meerkats spend half of their time underground. With the latest technology, we can now follow these animals into their worlds, and that's mindblowing.

The cameras aren't a gimmick – we worked closely with biologists and zoologists to try to answer the questions they have about the animals they're studying. With the fur seals in Australia, the scientists knew how long the seals were spending at the bottom of the ocean and how frequently they dived, but with the cameras we could reveal exactly how – and what – they were hunting. We want to find out as much as possible about these animals so that we can preserve them for the future.

Filming from the animal's point of view is a great idea – why hasn't it been done much before?
Up until now, the technology just wasn't up to it – the cameras were too big and heavy, the picture quality was too poor, and the batteries didn't last for long enough. Now we can make tiny, high-quality cameras, and batteries are much lighter thanks to lithium polymer technology.

All of the cameras we used in this series were either built from scratch or greatly adapted from existing action cameras such as the GoPro. Battery life was still the main limiting factor, so we programmed the cameras to come on at key times when we knew the animals would be active – at night, for instance, or when they dived down to the depths. The cameras needed to be rugged, especially if we wanted to work with chimpanzees or brown bears, and the harnesses were designed so that the animals could easily pull them off if they wanted to – we didn't want them to interfere with the animals' behaviour.

What was the most surprising story that you uncovered?
Every year, hundreds and hundreds of devil rays congregate at a huge underwater mountain – or 'seamount' – in the Azores in the Atlantic Ocean. With our cameras, we saw that the female fish are heavily pregnant – we could actually see the unborn pups kicking in their stomachs. We think that they go to the seamount to give birth, as there's an abundance of food there, and then mate with the males nearby soon after. It saves males and females having

to locate one another in the expanse of the ocean.

Which animal made the best 'cameraman'?
The cheetahs were breathtaking. Most creatures move around so much that it's a big struggle to get a stable image, but although cheetahs are the fastest living land mammal, their heads stay perfectly steady so that they can focus on their prey. The footage we got from the cheetahs' head-mounted cameras was spectacularly smooth – you wouldn't be able to do any better with CGI. I worry that these animals are slowly putting me out of a job!

The cameras allow the scientists to get a closer look at how animals live

02 FILL IN OUR DIARIES

2017 may only just be over, but we're already planning our year ahead. Here are six events and exhibitions to get excited about in 2018

SOMEWHERE IN BETWEEN
WELLCOME COLLECTION, LONDON
8 MARCH – 27 AUGUST
WELLCOMECOLLECTION.ORG

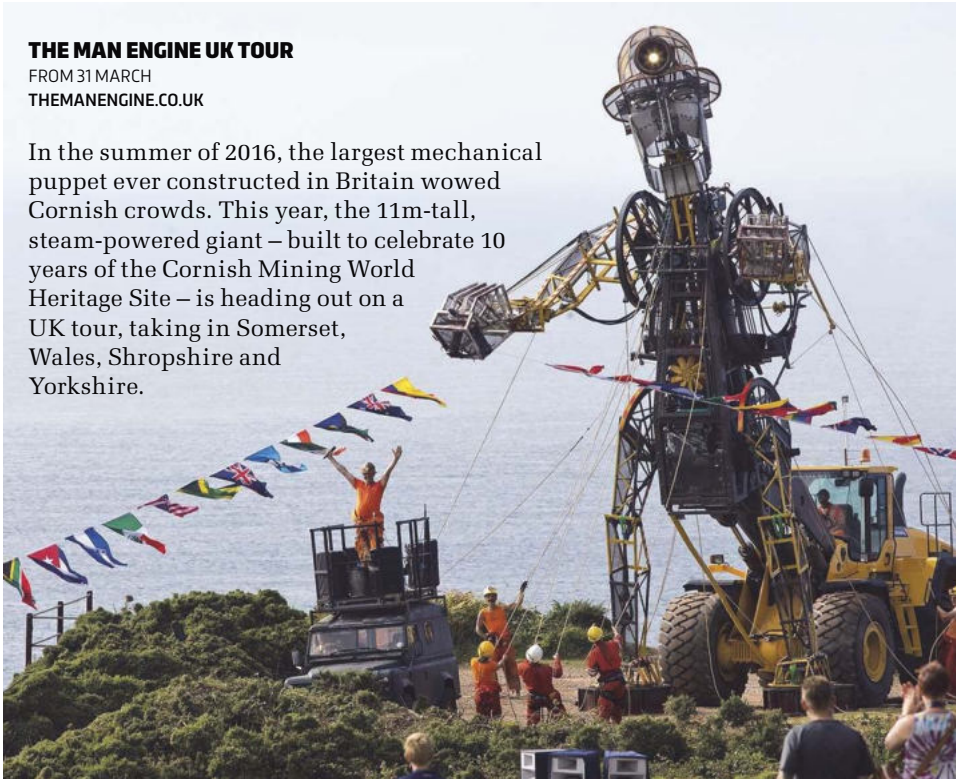
The Wellcome Collection is one of our favourite venues in London, and its first exhibition of 2018 brings together four intriguing collaborations between artists and scientists. The immersive installations will get visitors thinking about subjects ranging from synaesthesia to cattle breeding, free-diving, and HIV.

FESTIVAL OF SCIENCE: SPACE
ROYAL ALBERT HALL, LONDON
2 MAY - 28 JUNE
ROYALALBERTHALL.COM

The Royal Albert Hall's first science festival takes on a decidedly cosmic theme. Robin Ince and Chris Hadfield headline with their *Space Shambles* show, while other events include a children's concert, a performance from the BBC Radiophonic Workshop, and three classic sci-fi film screenings backed by live orchestra.

THE MAN ENGINE UK TOUR
FROM 31 MARCH
THEMANENGINE.CO.UK

In the summer of 2016, the largest mechanical puppet ever constructed in Britain wowed Cornish crowds. This year, the 11m-tall, steam-powered giant – built to celebrate 10 years of the Cornish Mining World Heritage Site – is heading out on a UK tour, taking in Somerset, Wales, Shropshire and Yorkshire.



Sculptures like this one will be on display at *The Future Starts Here*

THE FUTURE STARTS HERE
VICTORIA AND ALBERT MUSEUM, LONDON
12 MAY – 4 NOVEMBER
VAM.AC.UK

The V&A is looking to the future with this major exhibition exploring the ways in which powerful design is shaping tomorrow's world. There'll be more than 100 objects on display, including a chargeable shirt that can power a smartphone, and Facebook's elegant *Aquila* aircraft.

GREAT EXHIBITION OF THE NORTH
NEWCASTLE & GATESHEAD
22 JUNE – 9 SEPTEMBER
GETNORTH2018.COM

Billing itself as the largest event in England in 2018, this looks set to be a summer-long feast of art, culture, design and technology. One of the highlights announced so far is the return of the iconic locomotive Stephenson's Rocket. It will be brought back to Newcastle, the city in which it was built in 1829.

***Somewhere In Between* will give visitors an immersive experience**

INTIMACY
SCIENCE GALLERY, DUBLIN
19 OCTOBER 2018 – 3 FEBRUARY 2019
DUBLIN.SCIENCEGALLERY.COM

Dublin's Science Gallery celebrates its 10th year with exhibitions including this exploration of intimacy in all its forms. Does absence really make the heart grow fonder? Can intimacy emerge between enemies? And how are our gadgets affecting the ways in which we connect?

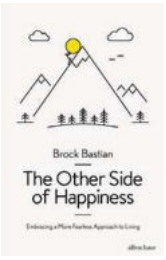
PHOTOS: BBC X3, MARTINA AMATI

03

FEEL THE PAIN

Generally, pain is something to be avoided: we tend to equate happiness with feeling comfortable. But, in his new book, psychologist BROCK BASTIAN argues that pain might just be the hidden ingredient to a fulfilled life

THE OTHER SIDE OF HAPPINESS
BY BROCK BASTIAN
OUT 25 JANUARY (£20, ALLEN LANE).



The main idea in your book is that we need some pain in our lives...
Happiness has become a focus of Western culture, and for many of us seeking happiness is an important goal in life. But we can't have endless happiness. If you think about it, that's actually quite a banal and horrible idea. We need the painful, negative experiences to know what happiness is – they give definition and meaning to our lives. We need to accept the negatives rather than try to medicate or eradicate them all.

We usually want to get rid of pain. What's the downside of eliminating it?
We're getting good at designing painkillers to take control of our pain, and in the developed world, we're more comfortable than ever, at least in the physical sense. But I think we're becoming *too* comfortable. Our ability to cope with discomfort is decreasing, and we sometimes feel like we shouldn't have to deal with pain at all. I'm talking about physical pain here, but you can draw parallels with other types of pain, such as social pain. Incidentally, a study has shown that taking painkillers not only reduces our negative experiences, but also our positive experiences. It seems that numbing our access to pain also numbs our access to pleasure. I'm not saying we should stop taking painkillers, of course, but I think there's a tendency to reach for them a little too readily.

We need contrast in life. A holiday is particularly enjoyable if we've had to work hard for it. Food tastes especially good after a long hike. By engaging with adverse or difficult experiences we increase our capacity to access pleasure in life. Yet, our societies tend to devalue these types of experiences. Our research at the University of Melbourne has shown that living in a society which expects us to be happy all the time actually seems to be driving depression. One of our studies involved tracking participants over a month as they kept daily diaries, and we found that social expectations were a central feature in people's depressive symptoms.

What are the benefits of pain?
Obviously it serves a physical function, telling us to take our hand away from a hot stove, but it also has more psychological benefits. For example, it helps with social connections. We're automatically attuned to other people's suffering, and it prompts us to reach out to others. In 2011, while I was researching this topic, there were huge floods in Brisbane, and 55,000 people came out to help with the clean-up.

So pain also makes us more generous?
About 12 months before the ALS Ice Bucket Challenge went viral in 2014, a study showed that people were prepared to donate more to charity if they'd just dunked their hand into ice-cold water. It was as if the pain gave more meaning to the act of giving. I doubt the Ice Bucket Challenge would have been so effective if people had been throwing confetti over themselves.

And pain also makes us more resilient. Research shows that the more we have to endure in life, the better we get at coping with it. Of course, too much trauma is damaging, but we need some exposure to challenging experiences in order to build resilience for the future.

How about chronic pain – surely that can never be a good thing?
No, I'd never want to pretend that anyone who's in chronic pain should be grateful for their experiences. I was invited to talk at the British Pain Society in front of anaesthetists who treat chronic pain, and I was a bit concerned at how my message would come across. But people were really interested in how this broader perspective can give people tools to respond to their pain. Even in chronic cases, some of the positive effects of pain can sometimes still be present. I'm not saying they outweigh the cost of chronic pain, but it can help give a more nuanced view of things – that pain is not simply 'bad'.

How can we put your ideas into practice in our lives?
First, we need to be authentic with our negative experiences, not pretend that they're not there. Sometimes life sucks – failure happens, and it is what it is. But the next step is to understand what these difficult experiences can offer us, and to see that we're often seeking out these negative experiences in the first place, even if it might not seem like it. We don't run marathons for the pleasure; we run them for the pain. The joy of passing an exam is meaningless without the possibility of failure. Finally, we need to embrace and engage with these experiences more. I'm not saying we need to cause ourselves harm – pain is not the same as harm. But a lot of pleasure in life comes from pushing ourselves and exposing ourselves to risks. I think that's the key to a meaningful life.

DON'T MISS

TRUST ME, I'M A DOCTOR

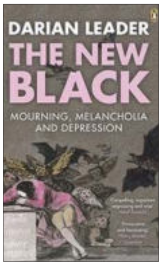
The series returns to BBC Two in January for six weeks. Among the questions being answered this time around are 'how much fruit is too much?', 'what can you do about baldness?', and 'can stress make you fat?'.

PHOTO: GETTY

Brock Bastian thinks that the pain of the ALS Ice Bucket Challenge contributed to its success

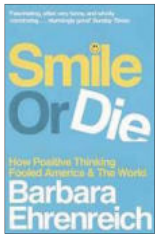
AUTHOR'S BOOKSHELF

Three books that inspired Brock Bastian while writing *The Other Side Of Happiness*



THE NEW BLACK: MOURNING, MELANCHOLIA AND DEPRESSION
BY DARIAN LEADER
(£9.99, PENGUIN).

"This book tackles issues of loss head-on. It invites us to mourn, not to step away and pretend everything is okay. It makes the case that this approach will loosen the grip that these experiences have on our lives."



SMILE OR DIE: HOW POSITIVE THINKING FOOLED AMERICA AND THE WORLD
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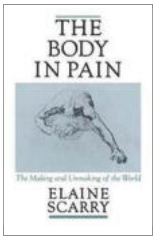
"I love the title of this book! It takes a no-prisoners approach to criticising the unrealistic and tyrannical nature of the positive thinking movement. It also warns against its costs, both in terms of human well-being and losing touch with reality."



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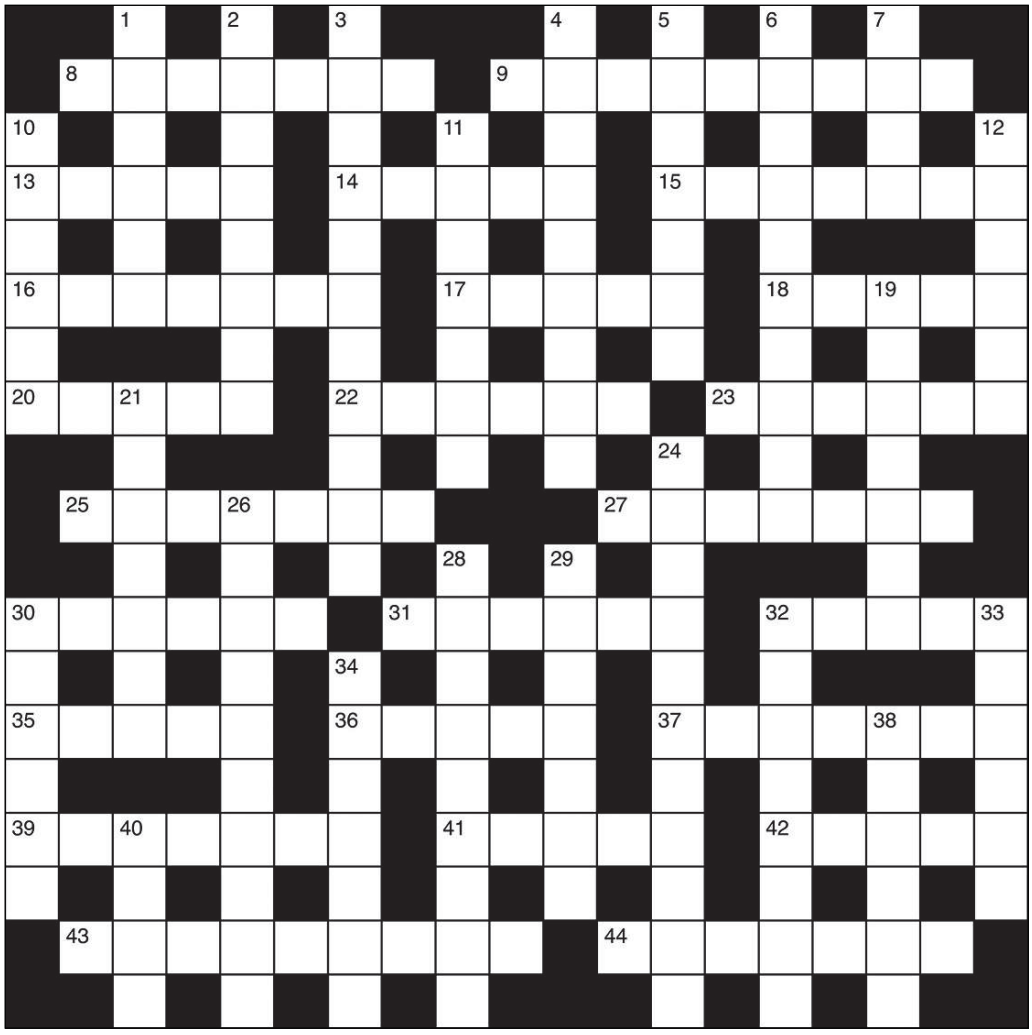

ACROSS

8 Leave playwright to kill top predator (7)
9 Performance of choirs, sir, gets a complaint (9)
13 Concentrate on what's in front of you (5)
14 Spoke repeatedly of raid carried out at one (5)
15 Crawler to stop at the surface (7)
16 Bully to mistake a flower (7)
17 Quietly warn about seafood (5)
18 Right to boot out an automaton (5)
20 Get Russian support included (5)
22 A feline in charge at a very small level (6)
23 Signal to have English breakfast outside (6)
25 Husband and wife have time for some poetry (7)
27 Notice keys to place of germination (7)
30 Name is altered to that of a French city (6)
31 Atoll in two pieces (6)
32 Instrument to fix stair (5)
35 Criticise Sigourney removing middle viola (5)
36 Muscle protein to do something at home (5)
37 Coat fashioned with bark, initially, and firm leaves (7)
39 Fertiliser expense involves old politician (7)
41 Starts to get edifice clean, kicking out lizard (5)
42 Strange graduate routine (5)
43 Drama had developed with unknown nymph (9)
44 Played role in a part of the wing (7)

DOWN

1 Supremo scowls about capital (6)
2 His play's about Chinese lantern (8)
3 Happy, say, with surface temperature on Pluto (5,6)
4 Using fingers, get one small drug (9)
5 Wife of Dionysus has a drain moved east (7)
6 Policeman finds dean a crawler (10)
7 Fraudulently manipulate a city (4)
10 Leaving copper time to get remnant (6)
11 Travelling road to get suitable, useful item (7)
12 Mark takes the first cholesterol-reducer (6)
19 European race pursuing US singer and dramatist (7)
21 Idealistic to turn to best Scot (7)
24 Toxic period averted by turning to the right (11)
26 Majestic girl, originally one of the Mint family (10)
28 That man has rags to distribute in graph (9)
29 British coin is spent on mechanical organs (7)
30 Overturn a limit on the French animal (6)
32 Minor variant of sandwich to reproduce (3-5)
33 Managed to get coordinate alright for Japanese inn (6)
34 Assault an energy supplier (7)
38 Everyday green (6)
40 Consume a lemon with lunch, say (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW** Please be aware the website address is case-sensitive.

MY LIFE SCIENTIFIC

James Wong

This New Year, ethnobotanist **James Wong** talks to **Helen Pilcher** about the magic of plants

According to James, eating more fruit and veg is the single best thing that you can do for your health in a dietary context. Don't bother with a faddy detox plan, though!

What is ethnobotany?
Ethnobotany looks at the ways humans use plants. Plants provide us with food, medicine, air and solutions to complex problems. For example, there's a way to extend the life of satellite solar panels that's based on the fibres of edelweiss flowers.

Do you know all the plants?
No one knows all the plants. We think there are around 300,000 species, but new ones are being found all the time. I'd like to be in *The Matrix*, where you could get a chip with all the plants on and plug it directly into your brain.

Tell me something surprising...
Plants can count. The Venus flytrap has hairs that sense insects, but the trap only shuts if the hairs are touched twice within 10 seconds. It then takes a further three touches, when the insect is struggling, for digestive enzymes to start being produced. The plant is counting two things: time and touches.

So plants are clever?
Plants can make decisions; they have complex social lives and can communicate with one another. Trees can detect plants that are closely related. They can shunt sugar along to feed their young, or stop growing their roots in that direction to avoid competition. If they detect an unrelated plant they react differently. I'm not describing plants as conscious, but they're making us rethink intelligence.

Yet some people find plants boring...
I'm always surprised by this. My mates who aren't into plants tell me that their first experience of them was being dragged round garden centres at five years old, looking at trays of bedding plants. It's no surprise then. They think about plants like shopping for soft furnishings!

What's your garden like?
I live in a tiny flat in central London so I don't have a garden, but I do grow a lot of plants indoors. Then one day I discovered I couldn't fit any more in. So I converted my coffee table into a giant terrarium. Now I grow plants in there.

What do you grow?
Things that are weird and wonderful, things I feel nostalgic about. I grow a lot of tropical plants from when I was a kid in Borneo. I'm currently interested in a Malaysian begonia with iridescent leaves that look electric blue or pink depending on the angle of the light.

Where is your favourite place?
The mountain rainforests of Latin America. These are pockets of forest, high above the regular rainforest, which have an incredibly high density of floral plants. There are hummingbirds and flowers with neon petals. It's like walking onto the set of *Avatar*.

Have you ever killed a plant?
Yes, I kill plants all the time. The most talented horticulturalists that I know all kill plants. There's this idea that people like me are born with green fingers, but we're not. We're just more persistent. If I can't get something to grow the first time, I just keep on trying.

James Wong is a Kew-trained botanist and a panellist on BBC Radio 4's *Gardeners' Question Time*.

DISCOVER MORE

To listen to episodes of *The Life Scientific* with top scientists, visit **bit.ly/life_scientific**

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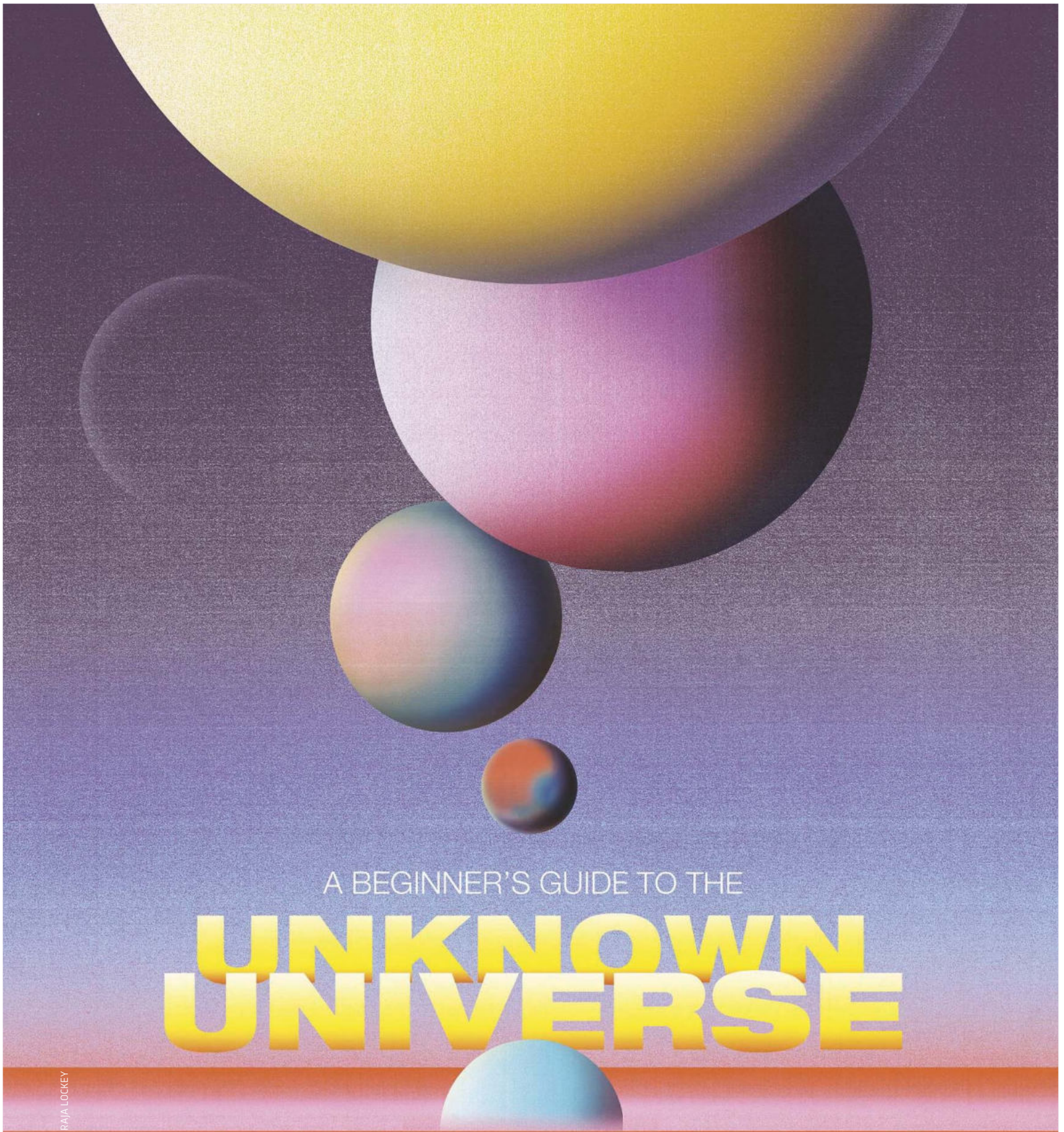
Nikon

At the heart of the image

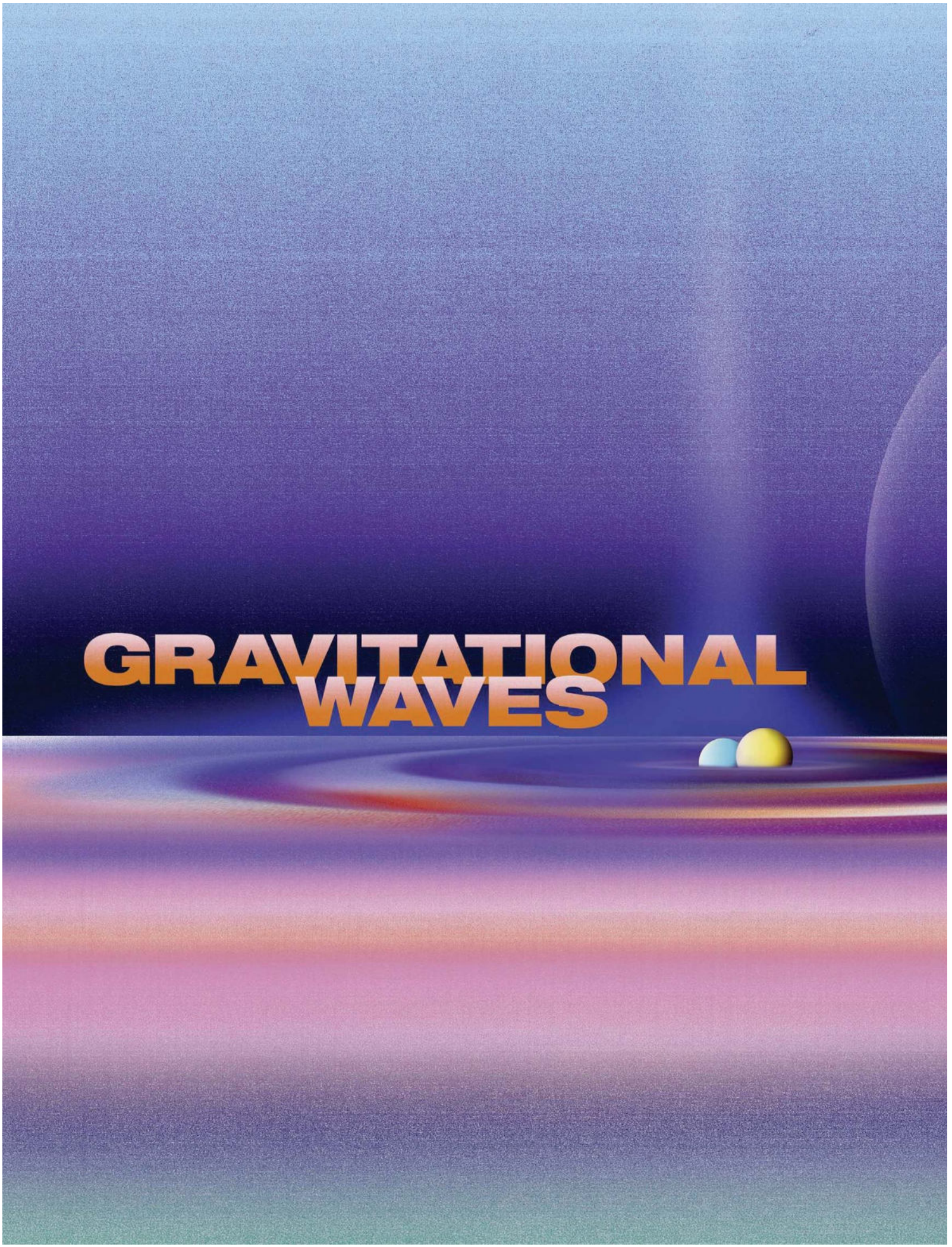


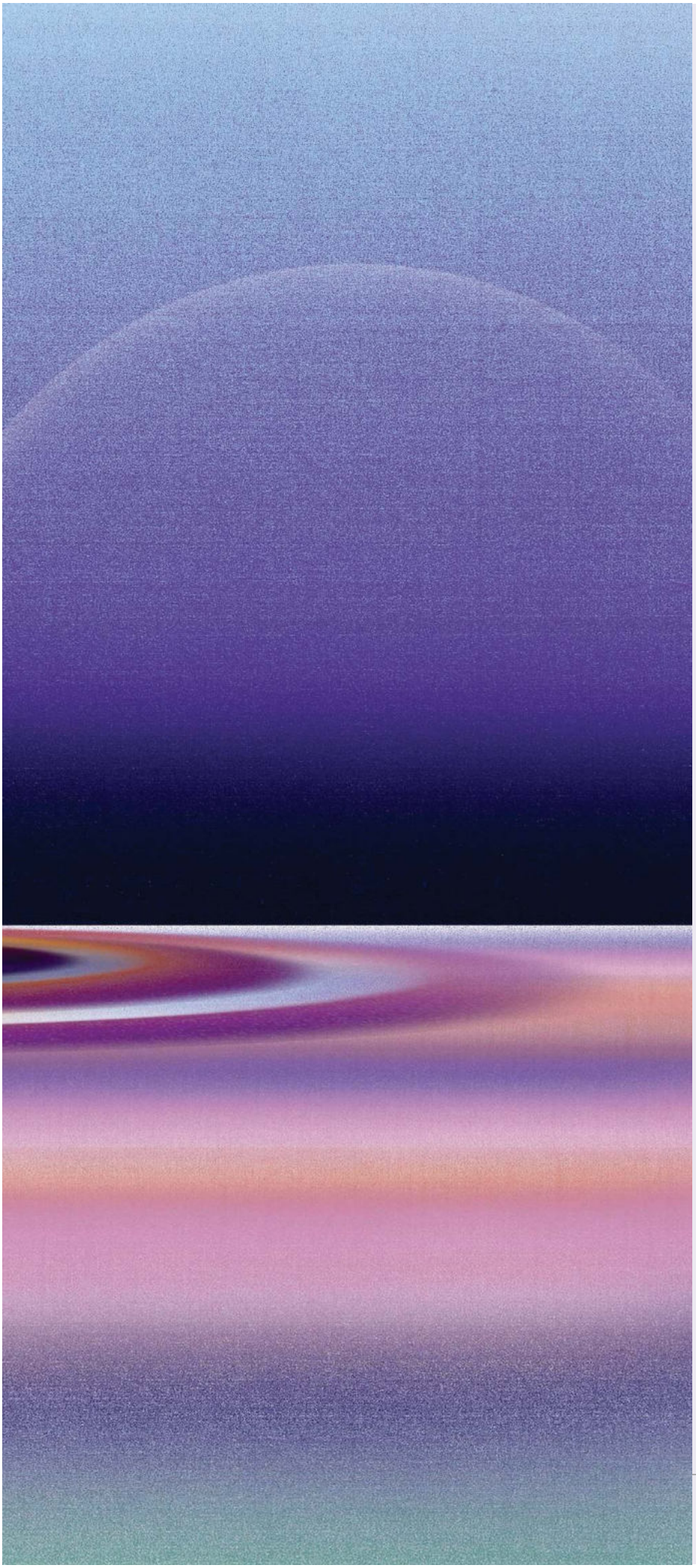
A BEGINNER'S GUIDE TO THE

UNKNOWN UNIVERSE

ILLUSTRATIONS: MERIJN HOS; GRAPHICS: RAJA LOCKEY

Breakthroughs in 2017 have opened up new frontiers in cosmology. We asked former Caltech radio astronomer and best-selling author **Marcus Chown** to give us the lowdown on the hottest topics in space right now...


GRAVITATIONAL
WAVES



Over 100 years ago, Albert Einstein predicted that space-time could be warped and stretched. It turns out, he was correct

Gravitational waves are ripples in the fabric of space-time. They were predicted to exist by Albert Einstein in 1916, although he then got cold feet and retracted his prediction the following year, only to re-make it in 1936.

Specifically, gravitational waves are a prediction of Einstein's revolutionary theory of gravity, the 'General Theory of Relativity', which he presented in Berlin in November 1915, at the height of WWI. Whereas Isaac Newton had maintained that there was a 'force' of gravity between the Sun and Earth, like a piece the invisible elastic tethering the Earth to the Sun and keeping it forever in orbit, Einstein showed that this is an illusion. No such force exists. Instead, the Sun creates a 'valley' in the space-time around it, and the Earth travels around the edge of the valley rather like a roulette bowl in a roulette wheel.

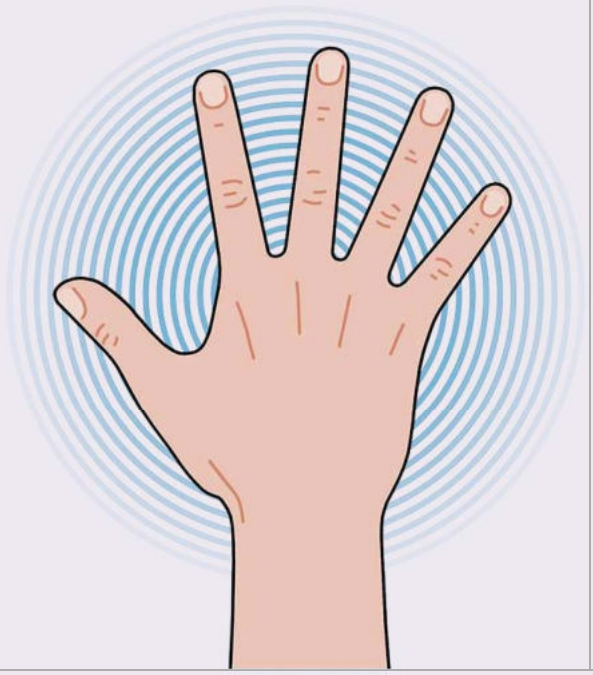
We cannot see the landscape of space-time because space-time – a seamless amalgam of three space dimensions and one of time – is a four-dimensional thing, and we are mere three-dimensional creatures. That is why it took a genius like Einstein to realise that what we think of as matter moving under the influence of the force of gravity is in fact matter moving through warped space-time. As the American physicist John Wheeler said: "Matter tells space-time how to warp and warped space-time tells matter how to move."

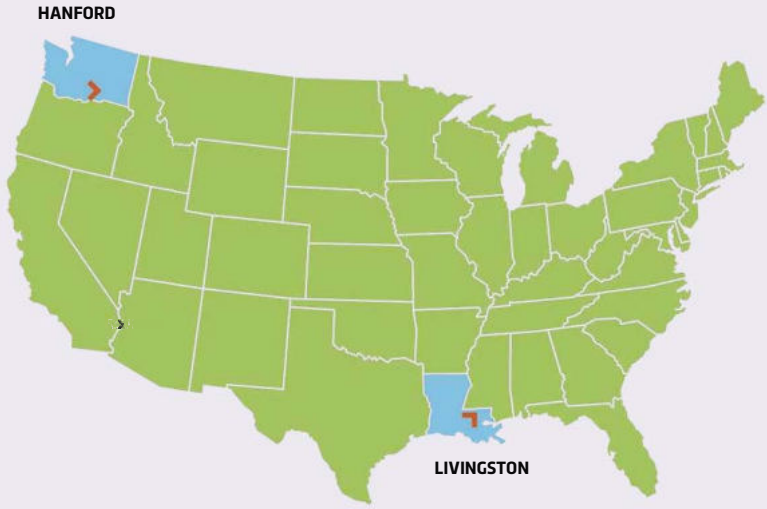
According to General Relativity, space-time is no mere passive backdrop to the events of the Universe. Instead it is 'thing', which can be bent and stretched and warped by the presence of matter. And, if it can be distorted in this way, argued Einstein, it can also be jiggled. When this happens, an undulation of space-time spreads outwards at the speed of light like concentric ripples on a pond: a gravitational wave.

HOW ARE GRAVITATIONAL WAVES MADE?

Wave your hand in the air. You just created gravitational waves. Already, they are rippling outwards through space-time. They have left the Earth. They have passed the Moon. In fact, they are well on their way to Mars. In about four years' time they will reach the nearest star system. We already know that one of the three stars of Alpha Centauri is circled by a planet. If it hosts a technological civilisation that has built a gravitational wave detector, at the beginning of 2022, it will be able to pick up the gravitational waves you created by waving your hand a moment ago!

Mind you, the detector will have to be super-sensitive. This is because gravitational waves, which are produced whenever mass changes its velocity, or 'accelerates', are extremely weak. The reason for this is that gravity itself is extremely weak. An equivalent statement is that space-time is extremely stiff. Imagine banging a drum. Now imagine replacing the drum skin with something a billion billion times stiffer than steel. That's the stiffness of space-time. This extreme stiffness means that only the most violent movements, such as the merging of super-dense bodies like neutron stars and black holes, can create appreciable gravitational waves.





ABOVE: **The two LIGO observatories are located 3,002km apart, in Hanford and Livingston**

10,000 billion billion billion billion

The factor by which the force of gravity is weaker than the electromagnetic force gluing together the atoms of your body.

44

Number of years between the construction of the first LIGO prototype at the California Institute of Technology in Pasadena and LIGO's first detection of gravitational waves.

1.3 billion

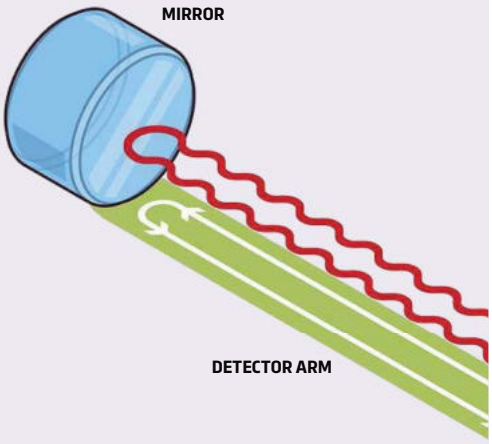
The number of years the gravitational waves detected on 14 September 2015 had been travelling across space to Earth.

5

Number of gravitational wave researchers so far awarded Nobel Prizes: Russell Hulse, Joseph Taylor, Rainer Weiss, Kip Thorne and Barry Barish.

99.999

Percentage of incident light reflected by the mirrors at each end of LIGO's four-kilometre 'arms'.



"AS GRAVITATIONAL WAVES PASS, THEY STRETCH SPACE IN ONE DIRECTION AND SQUEEZE IT IN A PERPENDICULAR DIRECTION, THEN ALTERNATE"

HOW ARE GRAVITATIONAL WAVES DETECTED?

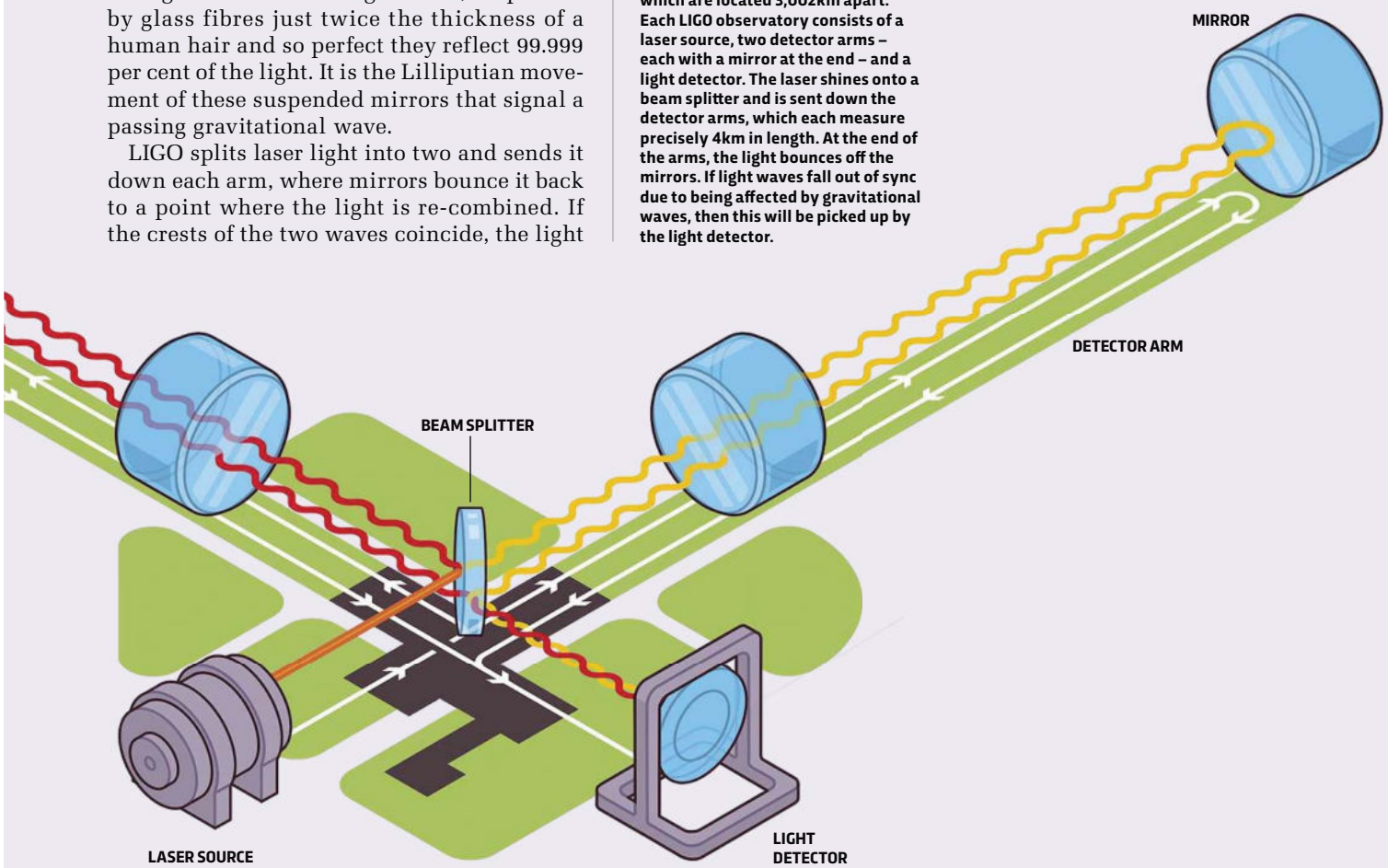
As gravitational waves pass, they stretch space in one direction and squeeze it in a perpendicular direction, then alternate, repeatedly. The effect felt on Earth of the waves from a black hole merger is extremely small, typically a change in the length of a body by a mere billion billionth of its size. Consequently, the only way to detect such a small effect is with a big ruler. Enter the Laser Interferometer Gravitational Wave Observatory (LIGO) – a 20th-Century technological marvel. At Hanford in the state of Washington is a four-kilometre ruler made from laser light. Three thousand kilometres away at Livingston, Louisiana, is an identical ruler. Each site actually consists of two tubes 1.2 metre in diameter, which form an L-shape down which a megawatt of laser light travels in a vacuum more empty than space. At each end the light bounces off 42kg mirrors, suspended by glass fibres just twice the thickness of a human hair and so perfect they reflect 99.999 per cent of the light. It is the Lilliputian movement of these suspended mirrors that signal a passing gravitational wave.

LIGO splits laser light into two and sends it down each arm, where mirrors bounce it back to a point where the light is re-combined. If the crests of the two waves coincide, the light detected is boosted. If the crest of one coincides with the trough of the other, the light is cancelled out. Consequently, LIGO is sensitive to changes in the length of one arm relative to the other of a fraction of the wavelength of light. A lot of ingenuity is expended in getting that measurement down even further to a hundred-thousandth the diameter of an atom.

At 5:51am EDT on 14 September 2015, first in Livingston, then 6.9 milliseconds later in Hanford, the rulers repeatedly expanded and contracted by a hundred-thousandth the diameter of an atom marking the first ever direct detection of gravitational waves.

THE LIGO EXPERIMENT

There are two LIGO observatories, which are located 3,002km apart. Each LIGO observatory consists of a laser source, two detector arms – each with a mirror at the end – and a light detector. The laser shines onto a beam splitter and is sent down the detector arms, which each measure precisely 4km in length. At the end of the arms, the light bounces off the mirrors. If light waves fall out of sync due to being affected by gravitational waves, then this will be picked up by the light detector.



SOURCES OF GRAVITATIONAL WAVES

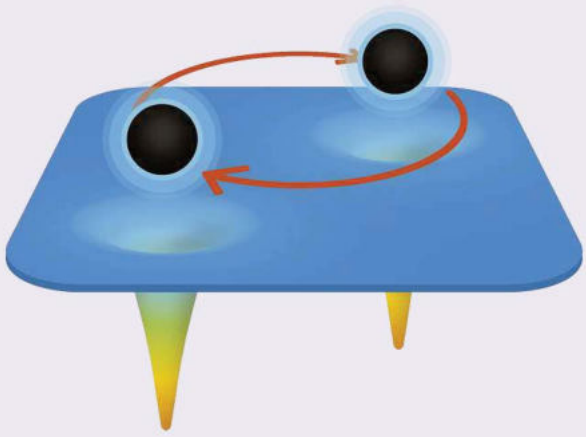
Neutron stars and black holes are the endpoints of the evolution of massive stars. When they explode as supernovas, paradoxically their cores implode. If the core is below a threshold mass, the stiffness of 'neutrons' – a so-called quantum property – can stop the shrinkage, leaving a star about the size of Mount Everest, but so dense that if you took a lump of its material measuring the same size as a sugar cube, it would weigh as much as the entire human race. If the core is above the threshold mass, no known force can stop the shrinkage and the star collapses to become a black hole.

Since most stars are born in pairs – our Sun being a rare exception – the expectation is that the most massive binaries end their lives as a pair of black holes, a pair of neutron stars, or a black hole orbiting a neutron star. The mere fact that the stars are orbiting each other – and changing their velocity, or accelerating – means that they radiate gravitational waves. This saps the stars of orbital energy, causing them to spiral in towards each other, at first very slowly, but, as time goes by, faster and faster.

Such an event, known as the 'binary pulsar', was observed for the first time in 1974, netting Russell Hulse and Joseph Taylor a Nobel Prize for the first indirect detection of gravitational waves. The first direct detection of gravitational waves, however, was on 14 September 2015. The source was two black holes of 29 and 36 solar masses in a galaxy located 1.3 billion light-years away. It is plausible that they had been spiralling together for most of the age of the Universe. However, only as they swung around each other for their last dozen or so orbits, at half the speed of light, were their gravitational waves strong enough for us to detect on Earth. First, there was a 'chirp', repeated roughly every 15 milliseconds. Then there was a final powerful burst of gravitational waves as space-time buckled and contorted and the two holes kissed and coalesced into a single giant black hole.

Six bursts of gravitational waves have now been detected, five of which were from merging black holes. But, on 17 August 2017, for the first time, a signal was picked up from merging neutron stars.

BEFORE MERGER

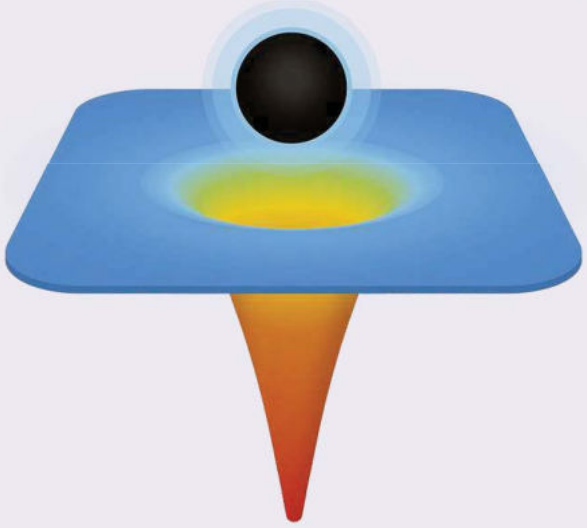


The two black holes were held in orbit around each other by their mutual gravitational pull. Their huge mass caused space-time to warp around them. Energy radiated away from them in the form of gravitational waves, leading to their orbits drawing closer.

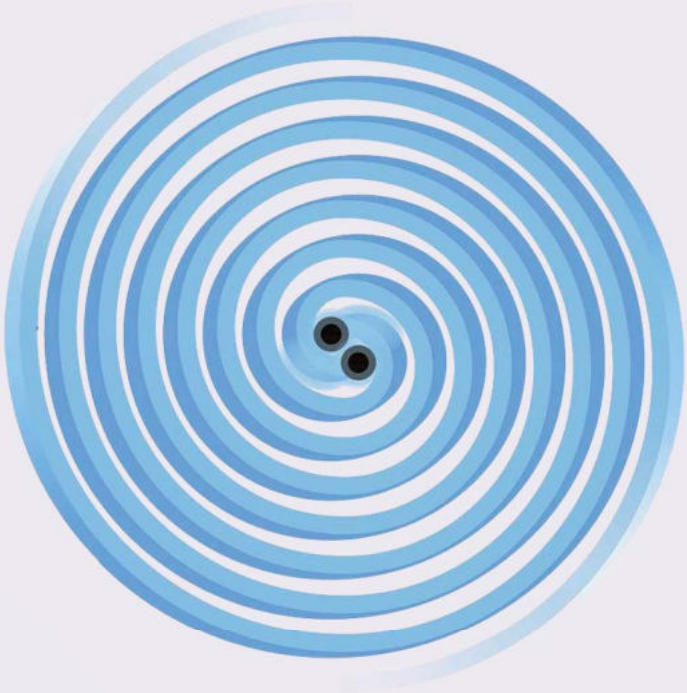
DURING MERGER

The black holes accelerated as they grew closer, reaching speeds close to the speed of light. Eventually, they merged into a single deformed black hole that radiated enormous amounts of energy as gravitational waves.

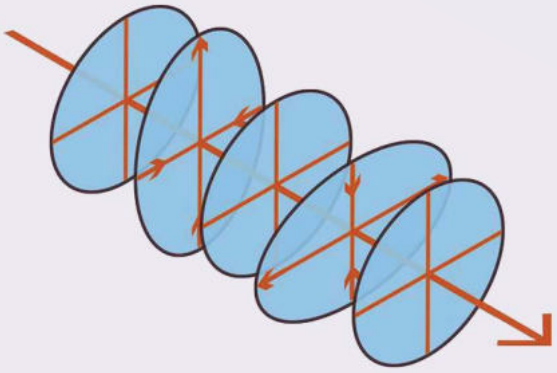
AFTER MERGER



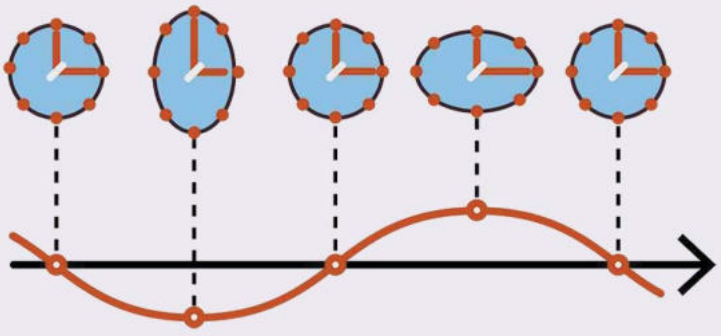
Once the black holes had merged into a single entity, the system settled into equilibrium with a regular spherical shape, and the emission of gravitational waves dropped rapidly. This is known as the 'ringdown'.



1. CATCH A WAVE
Einstein's General Theory of Relativity tells us that if two massive objects, such as two black holes, are bound together by gravity, they should create ripples in the fabric of space-time. These ripples are called gravitational waves.



2. SPACE GYMNASTICS
As a wave travelling at the speed of light passes through space-time, it first stretches space in one direction and squeezes it in the perpendicular plane, then reverses the process.



3. DETECT IT
On 14 September 2015, first in Livingston, then in Hanford, LIGO's arms repeatedly expanded and contracted by a hundred-thousandth the diameter of an atom, marking the first ever direct detection of gravitational waves.

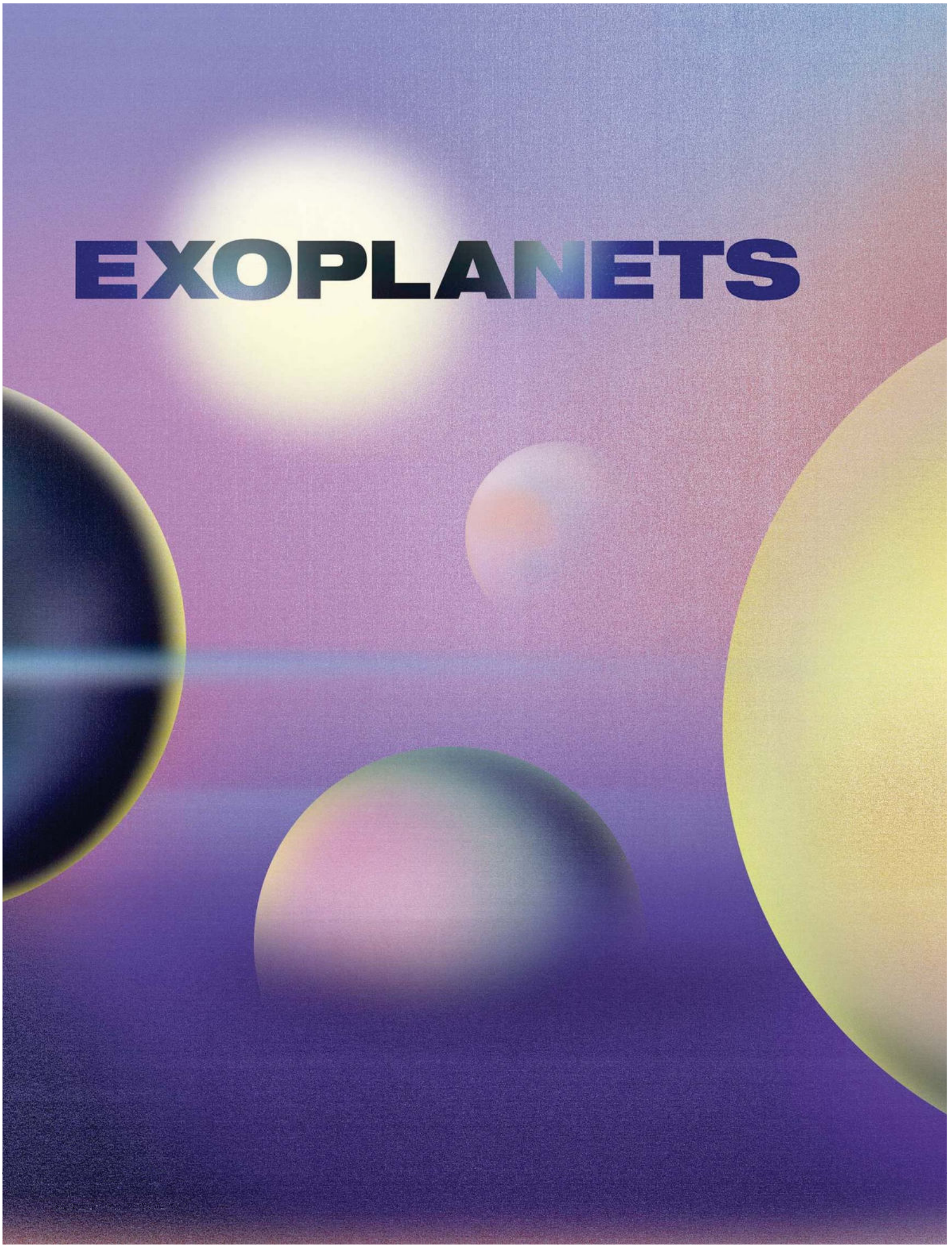
WHAT CAN GRAVITATIONAL WAVES TELL US?

Gravitational waves have the potential to point towards a better, deeper theory of gravity. We know that Einstein's theory breaks down in the infinitely dense 'singularity' found at the heart of a black hole and at the beginning of time in the Big Bang. The hope is that gravitational waves will lead us to a long-sought quantum theory of gravity.

They also have the potential to reveal the behaviour of super-dense matter inside neutron stars. Perhaps, even more excitingly, they could tell us about the birth of the Universe. In the standard picture, the Universe in its first split-second of existence went through an incredibly violent expansion known as inflation. This should have left a relic background of gravitational waves in today's Universe, which we may be able to detect and decode.

Gravitational waves truly provide us with a new 'sense'. We have always been able to see the Universe, with our eyes and telescopes. Now, for the first time, we can hear the Universe too. Gravitational waves are the 'voice of space'. So far, we have heard some sounds at the edge of audibility. Nobody knows what the cosmic symphony will sound like, but as we improve the sensitivity of gravitational wave detectors, we hope that we will discover things of which nobody has ever dreamed.

"THE HOPE IS THAT GRAVITATIONAL WAVES WILL LEAD US TO A LONG-SOUGHT QUANTUM THEORY OF GRAVITY"


EXOPLANETS

Planets lurking in solar systems many light-years away could help us learn more about the Universe and life itself

Exoplanets are planets that orbit stars other than our Sun. We now know of 3,493 exoplanets out there, and the number rises every week.

The first exoplanets were actually found orbiting the stellar corpse of a 'pulsar' by astronomers Aleksander Wolszczan and Dale Frail in 1992. However, the first exoplanet orbiting a Sun-like star was found by astronomer Geoff Marcy in 1999.

Now we have found extrasolar planetary systems containing five, six and even seven planets. ('Extrasolar' refers to astronomical objects located outside our Solar System.) About one-third of nearby stars have planets, and a further third have dust disks from which planets congeal. Consequently, in our Milky Way, there are almost certainly more planets than stars – and there are several hundred billion of those.

Before the discovery of the first extrasolar planetary system, the expectation was they would be like the Solar System, with rocky inner planets like Earth and Mars, and gas giant worlds like Jupiter and Saturn orbiting farther out. The shock has been that most extrasolar systems are utterly unlike ours.

Many extrasolar systems have giant planets, known as 'hot Jupiters', orbiting closer to their stars than the orbit of the Sun's innermost planet, Mercury. If they had been born there, their gas would have been blown away, so they must have formed farther out and 'migrated' inward. Many alien planetary systems have planets many times the mass of our Earth. Such 'super-Earths' are conspicuous by their absence in our Solar System, although there is a claim that such a planet, dubbed Planet Nine, orbits way beyond the outermost planet, Neptune.

In some extrasolar systems there are planets in highly elliptical orbits reminiscent of comets, and in others there are planets that share a single orbit. There are even planets that orbit the wrong way around their stars. Such 'retrograde' planets are hard to explain since planets are believed to congeal out of the leftover debris of star formation. Since the debris swirls around a star in a single direction, any planets should do too, as in our Solar System.

We thought we knew a lot about planet formation from studying our Solar System. But it turns out we have much to learn!

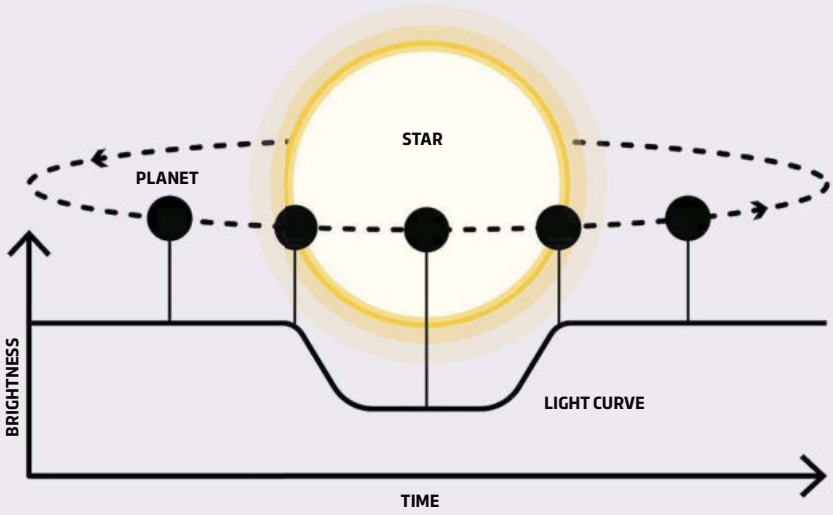
HOW DO WE DETECT EXOPLANETS?

Planets shine by reflecting the light of their parent stars. But since they are small compared with their stars, they are faint. And, since they orbit close to their stars, it is all but impossible to detect them directly. Think of a firefly flying in the beam of a search light. This means most exoplanets are instead found indirectly, through their influence on their parent stars.

One method exploits the fact that gravity is a mutual force: A star tugs on a planet but a planet also tugs on the star. This causes the star to wobble ever so slightly. The effect is hard to see on the sky but is quite easy to measure in the light of the star. As the star moves towards us and away from us, it creates a periodic shift in frequency of its light. This 'Doppler effect' is the light equivalent of a police siren becoming shriller (higher frequency) as it approaches and deeper (lower frequency) as it recedes.

The Doppler method reveals the time the planet takes to go around its star and the size of its orbit. If the star's mass is known, it can also provide a minimum possible mass for the planet. In 1995, a Swiss team led by Michel Mayor used this method to discover the first planet orbiting a Sun-like star: 51 Pegasi b.

Another method for finding planets is possible if the orbit of a planet regularly takes it across the face of its star as seen from Earth. Such 'transits' dim the light of the star slightly. If the size of the star is known, the dip reveals the size of planet. If its mass is known from the Doppler method, then its density can be deduced. Very few planetary systems are edge-on from our point of view, so observing transits requires monitoring huge numbers of stars.

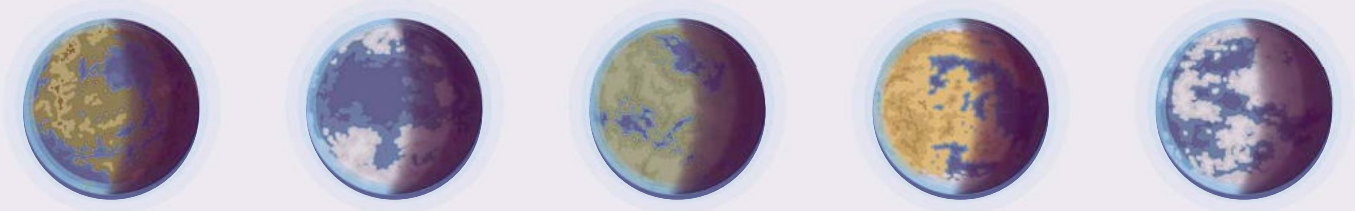


ABOVE: **If a planet's orbit regularly takes it across the face of its star, then the star's light will dip slightly, which means that the planet's size can be calculated**

Yet another method of finding planets relies on the focusing, or 'gravitational lensing' of the light of a more distant star, by a star and its planet. As the planet orbits its star, the brightness of the background star varies periodically, revealing the presence of the planet.

Though these indirect methods have proven successful, astronomers would like to be able to dispense with indirect methods and photograph extrasolar planets directly. In 2004, a group of astronomers reported the first detection of a giant planet candidate by direct imaging. Since then, several more have been imaged. The ultimate challenge, however, is to directly image an Earth-like planet.

THE FIVE MOST INTERESTING EXOPLANETS IN THE SEARCH FOR LIFE



PROXIMA CENTAURI B

This is an Earth-mass planet orbiting the cool red dwarf star, Proxima Centauri, once every 11.2 days. Being the closest exoplanet to Earth, it has the most exciting potential for observation.

TRAPPIST-1 E

This is just over half the mass of Earth and orbits its red dwarf parent every 6.1 days. It is one of seven known planets in the Trappist-1 system, three of which are in the Habitable Zone.

KEPLER-62F

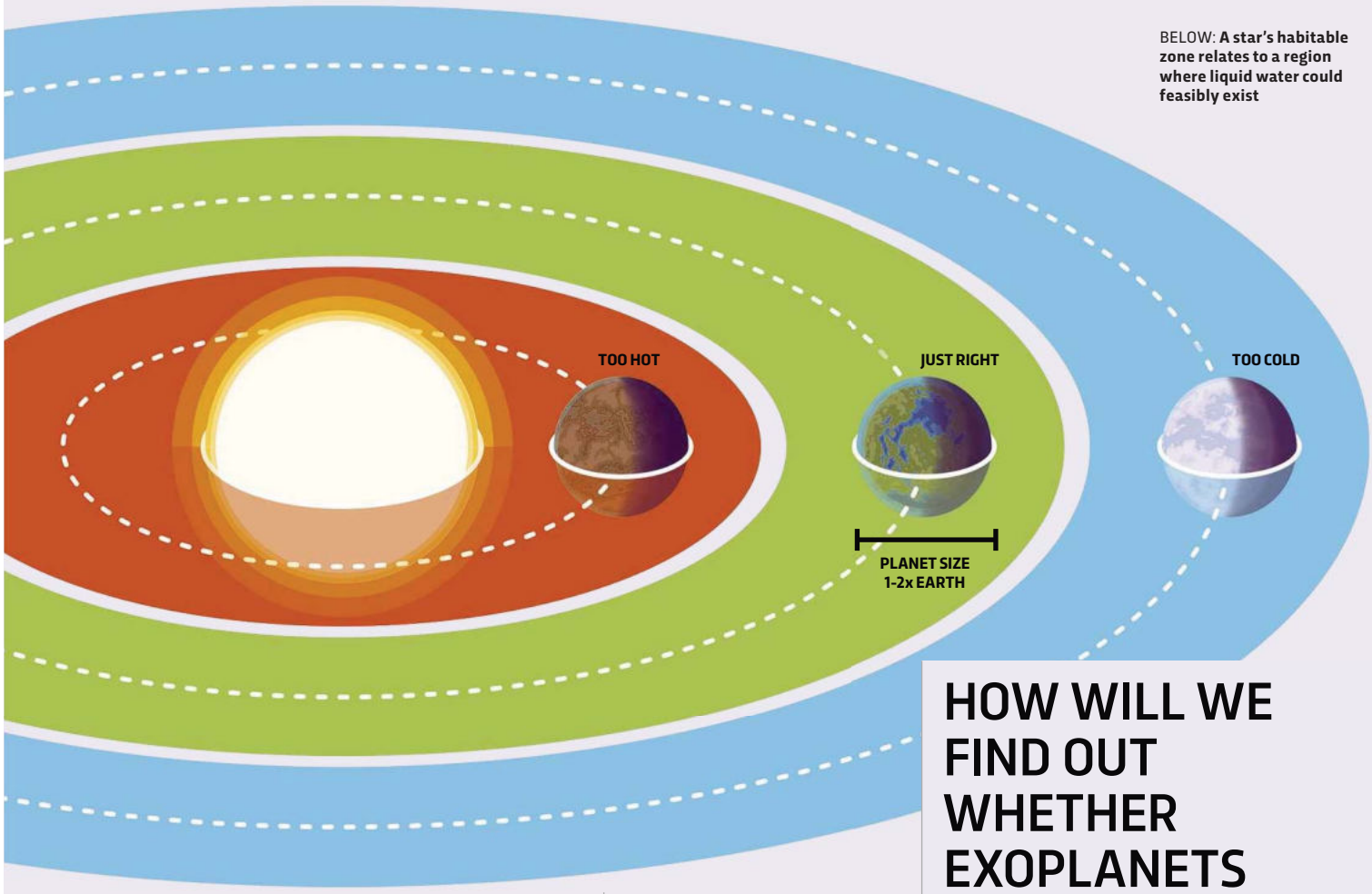
This has a mass about three times bigger than Earth's. It orbits a dwarf star once every 267 days. The star is cooler than the Sun, so for it to be warm enough for oceans, the planet needs a thick atmosphere.

KEPLER-186F

This is about 1.5 times more massive than the Earth. It orbits once every 130 days in the Habitable Zone of its parent star. It is colder than Earth but a thick atmosphere might make it cosy for life.

KEPLER-452B

This planet is about five times as massive as Earth and 60 per cent bigger. Crucially, it orbits a star like the Sun in just over one Earth-year.



BELOW: **A star's habitable zone relates to a region where liquid water could feasibly exist**

HOW DO WE KNOW WHAT EXOPLANETS ARE MADE OF?

"Never, by any means shall we be able to study the chemical composition or mineralogical structure of the stars," said French philosopher Auguste Comte in 1835. He was wrong, as was demonstrated within two years of his death. Atoms and molecules, when heated, shine with light at characteristic wavelengths (energies). And, if they are in the cool atmosphere of a star, then they absorb light at those very same wavelengths. This creates a series of black lines like a supermarket barcode in the stellar 'spectrum'. In the same way, when an exoplanet moves in front of its star, so that the starlight passes through the planet's atmosphere on its way to Earth, there is the potential to see the characteristic barcode of the substances in the planet's atmosphere.

So far, this technique has revealed a number of substances such as sodium, carbon monoxide, carbon dioxide and water in the atmospheres of extrasolar planets. The detection of molecular oxygen, an unstable gas, would indicate its continuous creation by living things.

27,710
Distance in light-years of farthest confirmed exoplanets, SWEEPS-04 and SWEEPS-11.

3,493
Number of known exoplanets.

165,000
The number of years it would take a modern spacecraft to reach Alpha Centauri, the closest star system to the Solar System.

41.32 trillion
Distance in km to nearest exoplanet, Proxima Centauri b.

4,300
Temperature in °C of the hottest exoplanet, KELT-9b.

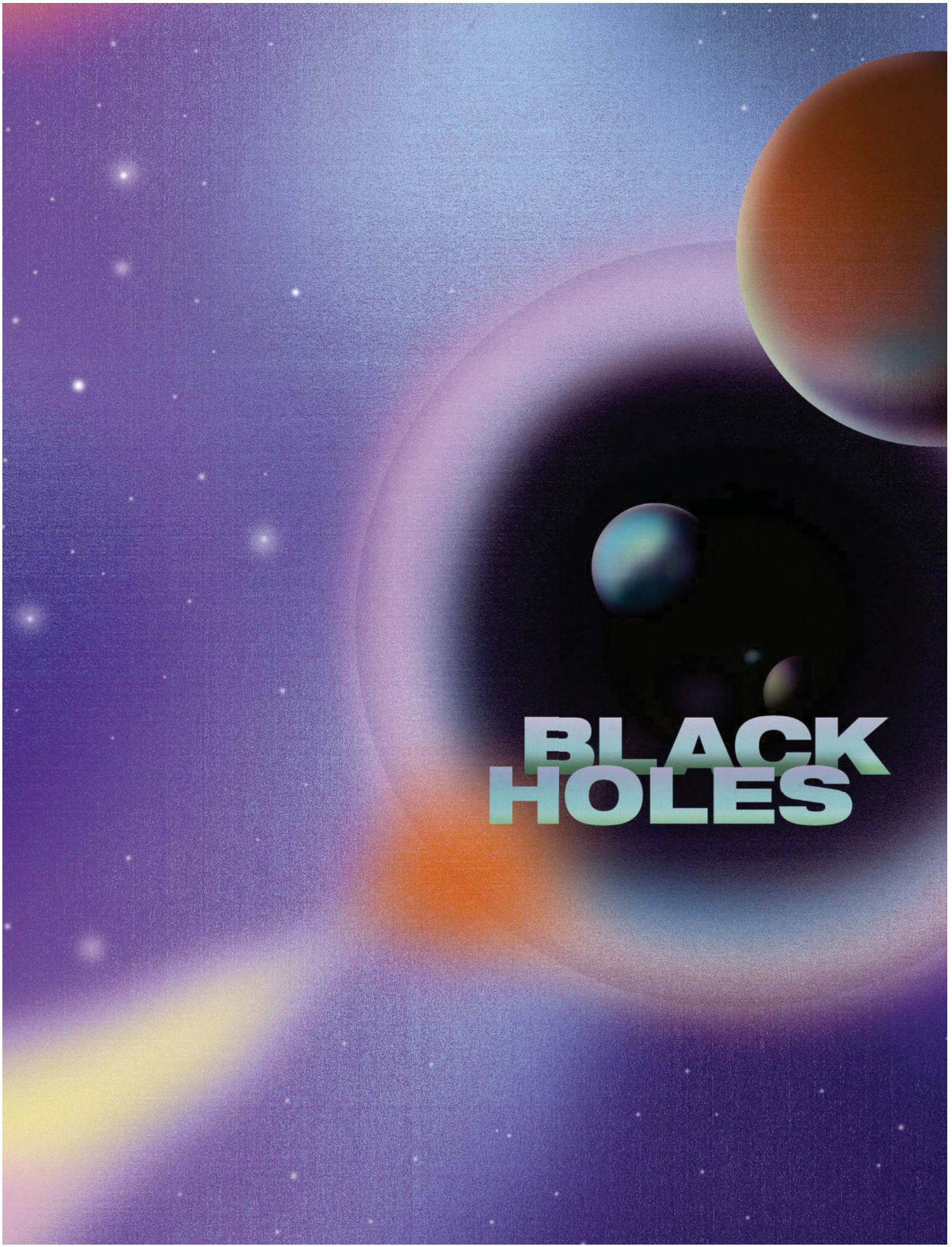
2.2
Length in hours of shortest year of any exoplanet, PSR J1719-1438 b.

HOW WILL WE FIND OUT WHETHER EXOPLANETS ARE INHABITED?

Since we have only one example of life – what's found here on Earth – we have no choice but to look for 'life as we know it'. And all life on Earth requires water. This has given rise to the idea of a star's habitable zone. A planet orbiting within this region is close enough to its star that water does not freeze and far enough away that it does not boil. This not-too-cold, not-too-hot 'Goldilocks zone' is quite narrow around the huge majority of stars, which are red dwarfs, but wider around Sun-like stars.

Recently, the concept of the habitable zone has been considerably widened. This is because of the discovery of ice-covered oceans located on Jupiter's moon Europa and Saturn's moon Enceladus. Although they intercept so little light that they should be frozen solid, they are heated by tidal stretching and squeezing from their parent planets. There is also the possibility that a planet orbiting far from its star might be kept warm by radioactive heat from its own rocks if it is swaddled in a blanket of greenhouse gases.

Life, it seems, might survive in environments far removed from those on Earth.


BLACK
HOLES

These weird, yet fascinating bodies are characterised by gravity so immense that not even light can escape

Black holes are regions of space where gravity is so strong that nothing, including light, can escape. Hence a black hole's blackness. The modern picture of black holes is provided by Einstein's General Theory of Relativity. The theory tells us that a mass like the Sun creates a valley in the space-time around it, into which other bodies fall. In this picture, a black hole is a bottomless well from which light cannot escape without being sapped of every last shred of its energy.

For reasons we do not fully understand, nature appears to have created two main classes of black holes: 'stellar-mass' black holes and 'supermassive' black holes, ranging in mass from millions of times the mass of the Sun to almost 50 billion times its mass. There is some evidence of the existence of a class of black holes between stellar-mass and supermassive, but so far astronomers have found very few of these 'intermediate mass' black holes.

Stellar-mass black holes are the endpoint of the evolution of massive stars. However, nobody knows the origin of supermassive black holes, or why there appears to be one in the heart of pretty much every galaxy, including our very own Milky Way. It is a chicken-and-egg puzzle. Does a galaxy of stars form first, and then later a supermassive black hole in its heart? Or does a supermassive black hole predate a galaxy and form the seed about which a galaxy of stars congeals?

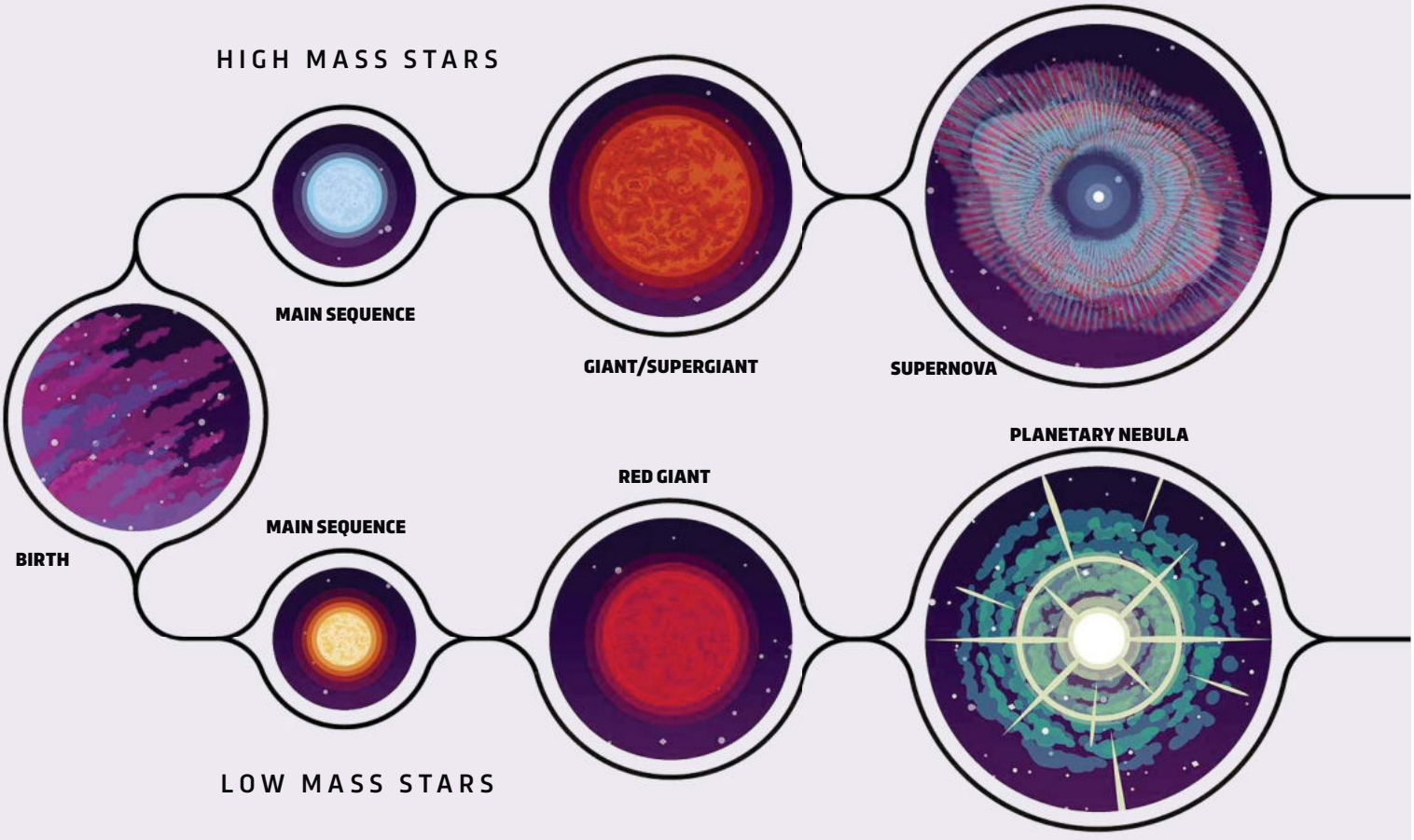
The heating of matter as it swirls down onto a supermassive black hole creates an 'accretion disk' so super-hot that it can pump out 100 times more energy than a galaxy of stars. This is the power source of active galaxies, the most energetic objects in the Universe.

THE LIFE CYCLE OF A STAR

A star is born when a cold, dark cloud of interstellar gas and dust shrinks under its own gravity. As the gas is squeezed ever smaller, it gets hotter. Eventually, when the core temperature exceeds 10,000,000°C, nuclear reactions ignite, and the ball of gas lights up as a star.

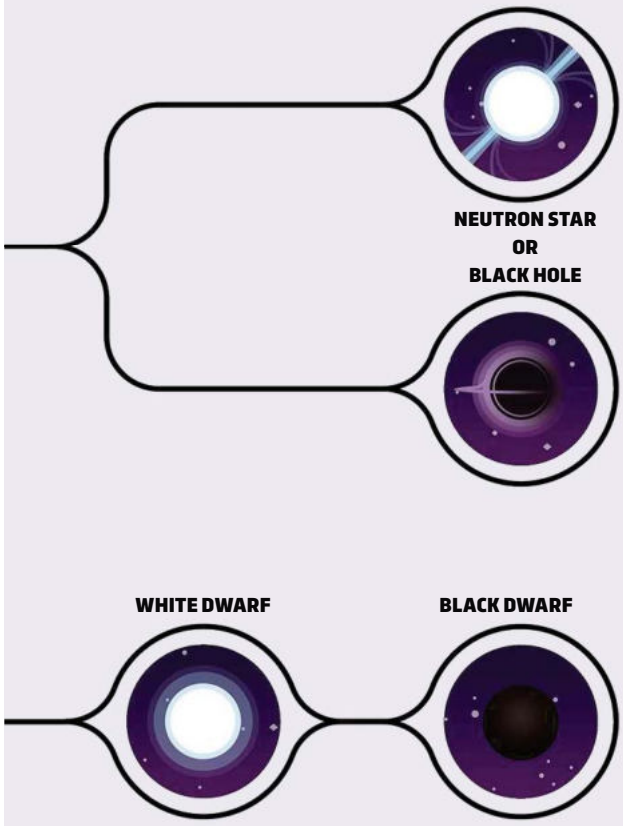
A star represents a temporary balance between the forces of gravity trying to shrink a ball of gas and its internal heat pushing outwards. The star fuses the cores, or 'nuclei', of hydrogen, the lightest atom, into the second lightest, helium. The mass difference between the initial and final product appears as the energy of sunlight, according to Einstein's famous formula $E=mc^2$. This conversion has an important effect on a star like the Sun. As helium is heavier than hydrogen, it falls to the centre. The nuclei of atoms repel each other, and the bigger the nucleus, the stronger the repulsion. For two new nuclei to stick together and make a heavier nucleus, they must slam into each other at high speed, which in practice means at high temperature since temperature is a measure of microscopic motion. The core of the Sun will only ever be dense and hot enough to fuse together hydrogen into helium. However, this is not the case with more massive stars. Their cores eventually become dense and hot enough to fuse helium into carbon, carbon into oxygen, oxygen into neon,

"A STAR REPRESENTS A TEMPORARY BALANCE BETWEEN GRAVITY TRYING TO SHRINK A BALL OF GAS AND ITS INTERNAL HEAT PUSHING OUTWARDS"

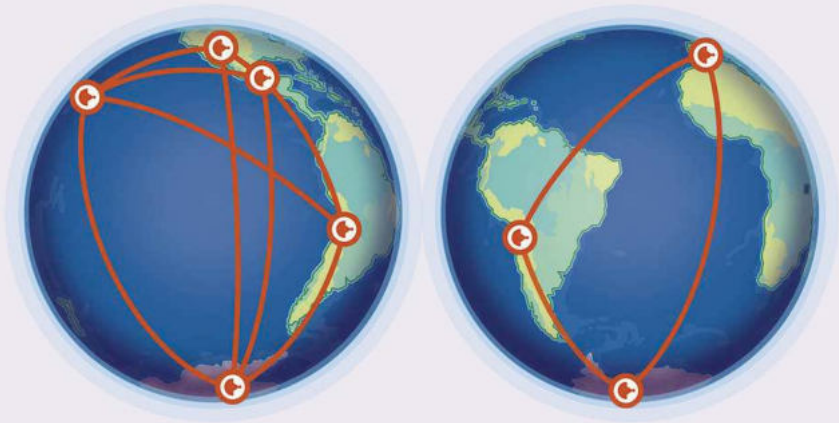


and so on. Such stars end up with an internal structure reminiscent of an onion, with the heaviest elements in the centre surrounded by concentric shells of less and less heavy elements.

The end point of this build-up process is iron. Its creation sucks nuclear energy from the core of the star. This causes the core to start shrinking, faster and faster, until a tiny, ultra-dense ball of neutrons, called a neutron star, is formed. In-falling material bounces off the neutron core, converting implosion into explosion – the explosion of a supernova that's so bright it can outshine an entire galaxy of stars. But, if the core is massive enough, no known force can stop gravity crushing the core out of existence – in fact, crushing it all the way down to a point of infinite density known as a 'singularity'. Cloaked in the impenetrable wall of an 'event horizon', this is a black hole.



LEFT: **Stars are born when a gas cloud collapses and matter accumulates on a protostar. A high-mass star is 10-150 solar masses (one solar mass = the mass of our Sun), a low-mass star is 0.08-10 solar masses. The main sequence takes up 90 per cent of a star's life – the Sun is currently at this stage. High-mass stars have shorter lives, and will become giants or supergiants before exploding into a supernova, where all but 10 per cent of the original mass is ejected. The star's core will then collapse. Depending on the size of the core's mass, it will either become a neutron star or a black hole. Low-mass stars have longer lives. After the main sequence, they will become red giants. Eventually, the outer layers of gas will be ejected and the star's core will contract to form a white dwarf. Theoretically, the star could then cool to form a black dwarf, but the Universe is still too young for this to be proved**



ABOVE: **The Event Horizon Telescope is a network of telescopes across the planet, which aims to photograph a black hole**

THE QUEST TO PHOTOGRAPH A BLACK HOLE

Stellar-mass black holes are difficult to see in detail because, one, they are small, and, two, they are black. The supermassive black holes in the hearts of galaxies are hugely bigger but unfortunately hugely farther away, making them appear small too. However, one supermassive black hole is both big and near.

Sagittarius A*, 26,000 light-years away in the centre of our Milky Way, weighs in at 4.3 million solar masses. It is the target of the Event Horizon Telescope (EHT), an array of cooperating radio telescopes scattered across the globe. The radio signals recorded at each site combined on a computer in Haystack, Massachusetts, to simulate a giant dish the size of the Earth. The bigger a dish is and the shorter the observing wavelength – EHT is using 1.3mm – the more it can zoom in on details in the sky.

The challenge is to image Sagittarius A*'s event horizon, which only appears as big in the sky as a grapefruit would appear on the Moon when viewed from Earth. What the astronomers want to know is whether the event horizon behaves as predicted by Einstein or even whether it exists. Recently, Stephen Hawking suggested that it might not. "An image would symbolise a turning point in our understanding of black holes and gravity," says EHT leader Shep Doeleman of the Massachusetts Institute of Technology.

The first image of a black hole event horizon may be obtained in 2018. Almost certainly, it will be an iconic image to rival the double helix of a DNA spiral or the Apollo 8 image of the Earth rising above the Moon.

THE ANATOMY OF A BLACK HOLE

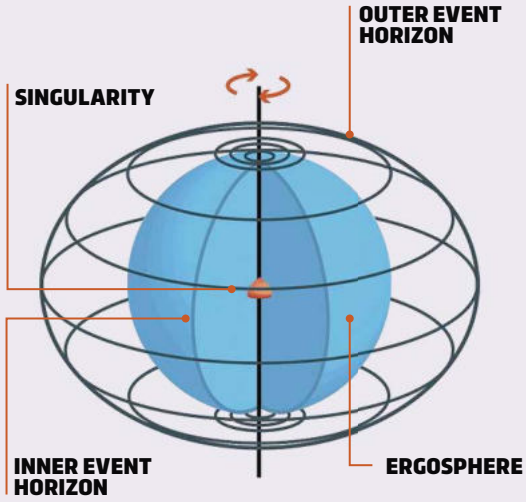
Once a massive star has shrunk to form a black hole, nothing is left (as far as we know) but a bottomless pit of space-time. A black hole is surrounded by an event horizon, an imaginary membrane that marks the point of no return for in-falling matter and light. Inside the event horizon, and at the heart of the black hole, Einstein's General Relativity predicts the existence of a point of infinite density called a 'singularity'. Yet once you reach the singularity, Einstein's theory – and all of physics as we know it – breaks down. Perhaps a new, quantum theory of gravity is needed to tell us what really exists there.

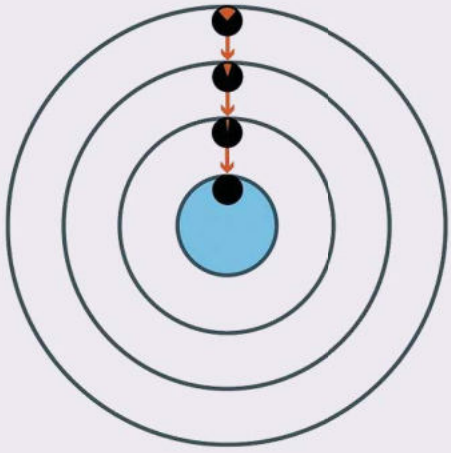
Imagine an astronaut falling feet first into a black hole. When they are at a circumference corresponding to 1.5 times the circumference of the black hole, gravity is so strong it bends light into a circle around the hole, so they can see the back of their head! Near a stellar-mass black hole, the huge difference in gravity between the astronaut's head and feet will tear them apart before they reach the event horizon. However, this tidal effect is negligible near a supermassive black hole, and the astronaut can cross the event horizon with no ill-effect.

Einstein's theory predicts that time flows more slowly in strong gravity. So, if you were to observe the astronaut falling down to the black hole from a safe distance, they would appear to move in ever slower motion, and stop altogether on reaching the event horizon. Although they would fall through into the hole, never to appear again, their image would be frozen on the event horizon, gradually fading as light from the image struggled to climb out.

In the case of a rotating, or 'Kerr', black hole, there is a twist. In effect, these have two horizons. When the astronaut crosses the outer one, and enters the 'ergosphere', they are dragged around by a tornado of space-time. They can still gain energy from the hole's rotation and be ejected from the black hole. However, once they cross the inner event horizon, there is no going back.

Nobody knows what the inside of a black hole looks like. However, space and time are so distorted that they swap places. The singularity therefore exists not across an interval of space but in the astronaut's future. Consequently, they can no more avoid reaching it and being crushed to death than you can avoid tomorrow.





ABOVE: **As a light source nears the event horizon, fewer and fewer photons are able to escape (shown in orange) from the black hole's gravitational clutches. Once the event horizon is reached no photons are able to escape.**

ABOVE: **The gravity of a black hole is so immense that it bends light into a circle round the hole. This means that someone falling in would be able to see the back of their own head.**

6

Diameter in kilometres of the black hole that would form if the matter of the Sun could be squeezed hard enough.

4.3 million

Mass in multiples of the Sun's mass of Sagittarius A*, the giant black hole at the heart of our Milky Way.

1.8

Diameter in centimetres of the black hole that would form if the matter of the Earth could be squeezed hard enough.

40 billion

Mass in Suns of the biggest known black hole in the Universe: S5 0014+81.

1

Diameter in metres of the Jupiter-mass black holes left over from the Big Bang which some have suggested could make up the Universe's invisible dark matter.

2 trillion

The probable number of supermassive black holes in the Universe: one in each galaxy.

Marcus Chown is an award-winning cosmology writer and broadcaster. His latest book is *The Ascent Of Gravity* (£16.99, Weidenfeld & Nicolson).